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THE ELECTRICAL EQUIPMENT OF AUTOMOBILES

A BOOK ON PRINCIPLES FOR MOTOR MECHANICS AND MOTORISTS

BY

STANLEY PARKER SMITH

D.SC., M.I.E.E., A.M.INST.C.E.

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LONDON
CHAPMAN & HALL, LTD.
1927

PRINTED BY THE WHITEFRIARS PRESS, LIMITED,
LONDON AND TONBRIDGE.

To

M. J. RAILING,

IN APPRECIATION OF HIS CONSTANT KINDNESS
AND THE ENCOURAGEMENT GIVEN THE
AUTHOR DURING MANY YEARS.

PREFACE

In response to requests from representatives of the motor trade in the Glasgow area, the present author gave a course of lectures last winter at the Royal Technical College, Glasgow, on "The Electrical Equipment of Automobiles."

The course was essentially practical and was intended to furnish information required by those engaged in the manufacture, maintenance, repair and running of automobiles. This small book embodies the material given in the course.

The reader is presumed to possess a knowledge of the fundamental laws of electricity and magnetism. Descriptive matter of a commercial nature —such as is to be found in makers' catalogues—has been consistently avoided ; the reader will therefore not expect to find in this work photographic reproductions or manufacturers' specialities.

An attempt has been made to give in plain terms a technical description of the action of essential parts of the electrical equipment of automobiles, such as the storage battery, starting motor, three-brush dynamo and cut-out, and of the common ignition systems.

All complications such as the "Dynamotor," "Magdyno," dual ignition, etc., which involve no fundamental principle not discussed in the sequel,

have therefore been rigorously excluded. It is felt that a sound understanding of the basic parts will enable the reader to follow the working of composite machines and complicated systems of wiring, the number of which appears to be legion.

Adequate consideration has been given to the proper maintenance of the appliances discussed, and due stress has been laid upon the methodical location of faults which occur in the several parts of the equipment.

The author has had great help in this work from members of his own staff. He is also greatly indebted for the ungrudging assistance given him by Mr. W. H. Glaser, Chief Engineer at the works of Messrs. C. A. Vandervell & Company, Limited. Mr. A. P. Young and Mr. L. Griffiths, of the magneto works of Messrs. British Thomson-Houston Company, Limited, have supplied valuable information on magnetos, and the Chloride Electrical Storage Company, Limited, on car batteries. Professor E. W. Patchett, M.A., has very kindly read through the manuscript.

It is hoped that the book will prove useful alike to motorists and motor-mechanics.

S. PARKER SMITH.

The Royal Technical College,
Glasgow.
September, 1927.

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ELECTRICAL EQUIPMENT OF AUTOMOBILES

CHAPTER I

THE STORAGE BATTERY

A STORAGE battery is necessary for electric lights and horn, starting motor and coil ignition.

Batteries have had an evil reputation in the past, and doubtless deserved it to some extent by their behaviour. Nowadays, however, they are made sufficiently robust to do their work. When, therefore, trouble occurs with modern batteries, constructed in view of specific function as parts of an automobile, the cause must often be attributed to improper maintenance or gross abuse. Such neglect is most likely to be due to ignorance. A battery out of order is a great nuisance, but the reader can be consoled by the assurance that with proper treatment it will give useful, continuous service for two or three years; if only used occasionally, its life may be longer.

A battery is not a thing that can be left to look after itself; nor can any set instructions or rules, nor any such simple device as omitting the switch to keep the battery on charge whenever the vehicle is running, be satisfactory. The user is advised to

study the conditions governing his own particular case, and to treat his battery accordingly. This is not a difficult matter when the elementary principles underlying the use of storage batteries have once been grasped.

Car cells must have maximum capacity for minimum weight and volume. When starting the engine, they must be capable of giving 100 to 300 amperes for five, ten or more seconds. The current density for this purpose must be five to ten times as much as in stationary batteries. Thick plates are obviously stronger, but for such large starting

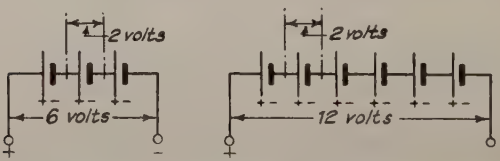

FIG. 1.—Cells in series to form 6- and 12-volt batteries.

currents the plates must be thin in order to obtain large surface area for given weight, and to shorten the time for the changed acid in the paste to diffuse out and new acid to diffuse in. Thus the automobile battery is a special development, and differs widely in construction from batteries intended for other purposes. The life of a car battery is about 150 complete cycles of charge and discharge, but in autocar work a complete cycle is seldom effected.

Definition and Types of Storage Batteries.—In addition to the name " storage battery," the names " secondary battery " and " accumulator " are also used. A battery consists of a number of cells,

which, in the application we are considering, are joined together or "placed in series" to give the required voltage—usually 6 or 12 volts—the negative terminal of one cell being joined to the positive terminal of the next and so on (see Fig. 1). There are two types of cells used on vehicles, the iron-nickel or alkali cell and the lead-acid cell.

The *iron-nickel* cell has a voltage of 1·3 to 1 volt on normal discharge. It has a large voltage drop on heavy discharge, which is a drawback for use with starter motors, although it is very robust and can withstand short-circuit with impunity. It is used principally in electrically-propelled vehicles.

The *lead-acid* cell is the only one with which we shall concern ourselves here. This cell has a voltage of 2·0 to 1·85 volts on normal discharge, and 1·8 to 0·9 volts on heavy discharge, as when the motor starting switch is closed. In a 6-volt system, therefore, a battery will contain three such cells, and in a 12-volt system six cells (see Fig. 1).

Action of Lead-Acid Cell.—A cell does not store electricity. Its action depends on the conversion of energy. During charge, electrical energy is converted into chemical energy; during discharge, chemical energy is converted into electrical energy.

In the ordinary lead-acid cell the active materials are lead oxide (PbO_2) on the positive plates, and finely-divided or spongy lead (Pb) on the negative plates. These active materials are held in cast lead grids which are immersed in a solution (approximately 25 per cent.) in water of sulphuric acid (H_2SO_4), called the electrolyte. The positive and negative grids are cast with lugs, to which the

terminals of the cell are attached. Each cell is accommodated in a sealed container of moulded material, or in a lead container sealed with pitch into an outer wooden case. The cells are joined in series by burnt or bolted lead connections.

When current is taken from the cells chemical changes take place, whereby some of the lead oxide on the positive plates and some of the spongy lead on the negatives is converted to lead sulphate ($PbSO_4$). During this process sulphuric acid is reduced and water (H_2O) is formed, which accounts for the lowering of the density or specific gravity of the electrolyte as the discharge proceeds. Only a small proportion of the total amount of active material is involved in this chemical change. To charge the cells, current is sent through the battery in the opposite direction, viz., from positive to negative, and the reverse action takes place, lead sulphate being converted to lead oxide on the positive and reduced to spongy lead on the negative plates, while the density of the electrolyte rises due to the reconversion of water into sulphuric acid.

These conversions can be represented as follows :—

During charge.			During discharge.		
Positive plate.	Electro-lyte.	Nega-tive plate.	Positive plate.	Electro-lyte.	Nega-tive plate.

$$PbO_2 + 2H_2SO_4 + Pb = PbSO_4 + 2H_2O + PbSO_4$$

It is not permissible to convert the whole of the active material in this way ; as explained later, discharge must be stopped when the voltage falls to 1·7 volts.

Charging.—During the process of charging, the

voltage between the terminals of a cell rises slowly to 2·4 to 2·5 volts, and then rapidly to 2·6 to 2·75 volts, the nature of the rise depending on the charging current (see Fig. 2). The cell is then fully charged, and the density of the electrolyte will be 1·28 to 1·3, depending on the original dilution of the acid. In addition to the voltmeter, which indicates the cell voltage, and the hydrometer, which indicates the density of the electrolyte, further indications that the cell is fully charged when a current is still passed through it are given by "gassing," that is, by numerous gas bubbles being given off at the plates, and by a rise in temperature of the electrolyte.

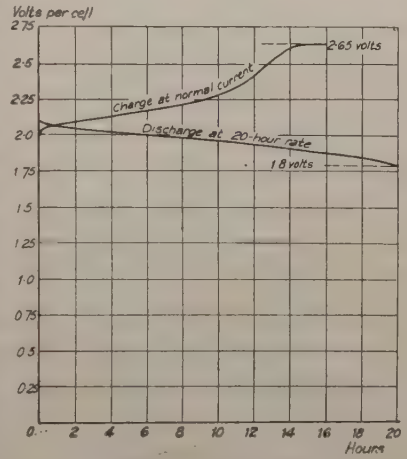

Fig. 2.—Typical charge and discharge curves of a car cell.

As soon as the charging current is switched off from a fully-charged cell the voltage at once drops to 2·25 volts, and then settles down slowly to between 2·1 and 2·0 volts.

Discharging.—The voltage on discharge depends on the rate of discharge. With a normal discharge current, the voltage falls off somewhat as shown in Fig. 2. Under a heavy discharge rate, however, as

when starting the engine, the fall is more rapid, and the cell only approaches or recovers its normal voltage after a more or less protracted rest. Should the engine not start with the first trial, the battery should be given a brief rest before a second attempt, to enable new electrolyte to diffuse into the pores of the plates. The voltage of a cell falls off very rapidly as soon as it drops below about 1·7 volts. When this stage is reached, the density of the electrolyte in a car cell will have fallen to the neighbourhood of 1·15, due to the conversion of some of the sulphuric acid to water, and the cell should be recharged forthwith. To carry discharge further is not only decidedly harmful, but it is practically useless, as very little more energy is obtainable from a battery in this condition.

The Hydrometer.—It has been seen that during charge the density of the electrolyte gradually rises. When the cell is fully charged, this reaches about 1·28, though some makers force their cells somewhat by using stronger acid and going to 1·3 or 1·31. In this way rather greater capacity with a given weight is obtained, though at the expense of shortening the life of the cell. On discharge, the density falls, reaching about 1·15 on full discharge. Consequently the density or specific gravity of the electrolyte is a measure of the state of charge of the cell, and is a more reliable guide than the voltmeter, for reasons that will appear later.

Every one concerned with batteries, therefore, should accustom himself to test his cells from time to time by measuring the density of the electrolyte by aid of a hydrometer.

How to Use a Hydrometer.—A form of hydrometer commonly used for testing car batteries consists of a glass or celluloid tube containing a graduated float, as shown in Fig. 3. At one end of the tube is a rubber bulb, and at the other end is a rubber extension for inserting into the cell. Before removing the stopper from each of the cells, it is well to remove any moisture or dirt in, on or near the battery. In using the hydrometer it is also well for the observer to place himself as advantageously as circumstances permit, to enable him to get reliable readings. Insert the rubber extension below the level of the electrolyte and draw in enough electrolyte to raise the float; then read the level of the liquid at the base of the meniscus (see Fig. 3). Repeat the test and compare the second reading with the first. In case of disagreement, repeat tests until agreement is obtained.

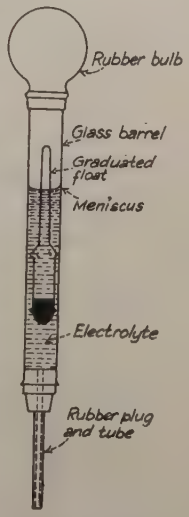

FIG. 3.—Car-battery hydrometer, showing meniscus.

This test is not hard to carry out, but patience and care are needed to carry it out properly. Do not try to fill the hydrometer with electrolyte and then squirt out the excess. Draw in as much as is necessary for the purpose, and no more. It is also well, when reading, not to withdraw the hydrometer right out of the cell, but merely to raise it above the level of the acid. Be careful to return any electrolyte to

its own cell. There are a few further precautions to be borne in mind. Be sure that the float does not stick to the walls of the tube. After " topping up," do not take the density until the cells have been charged, for only then is the electrolyte thoroughly mixed. Do not hold a naked light near the battery for fear of an explosion due to the release of oxygen and hydrogen by electrolysis. Remember that it is sulphuric acid you are dealing with. Do not let it come near your clothes or any metalwork, and make a habit of washing your hands after testing your battery.

Effect of Temperature on Density of Electrolyte.— Density is affected by temperature. The hydrometer readings are to be taken as correct at a temperature of 60° F. Below this temperature the hydrometer reads too high, and above it too low. To correct for this, subtract 0·001 from reading for every $2\frac{1}{2}$° F. below 60° F. ; and add 0·001 to reading for every $2\frac{1}{2}$° F. above 60° F.

Examples :—

(i) Hydrometer reading at 40° F. = 1·275

Correction $\frac{60 - 40}{2\frac{1}{2}} \times 0{\cdot}001$ = 0·008

True density = 1·267

(ii) Hydrometer reading at 75° F. = 1·260

Correction $\frac{75 - 60}{2\frac{1}{2}} \times 0{\cdot}001$ = 0·006

True density = 1·266

Effect of Overcharging.—Strictly speaking it is not possible to give the battery an overcharge, because, when the battery is fully charged, a further passage of current produces electrolysis of the water in the electrolyte, oxygen being given off at the positive, and hydrogen at the negative plate. This highly explosive mixture renders it dangerous to hold a naked light near a " gassing " cell. The fully-charged state is evidenced by a rapid evolution of gas bubbles, known as " gassing." Consequently, if overcharging is persisted in, water is driven off and must be replenished (known as " topping up "). For this reason it is desirable to have a charging switch to cut out the charging dynamo when necessary. With coil ignition the risk of overcharging is reduced, and some makers deliberately omit the switch with this system.

Other bad effects of overcharging are over-heating, loss of acid through spray, and dislocation of active material from the plates.

(*a*) *Over-Heating* is the result of passing an excessive current through the cell towards and after the completion of the charge. The temperature should not be allowed to exceed 110° F., and if a battery on charge should attain this temperature, the current should either be reduced or interrupted forthwith.

(*b*) Acid *spray* is caused by acid being thrown off with bubbles during gassing.

(*c*) *Dislocation of Active Material* is produced by sending too large a current through the battery towards the end of the charge. Dislodged active material not only reduces the capacity of the battery, but may cause internal short-circuits.

It will be gathered that a battery can be ruined by overcharging as well as by undercharging. (See "Adjustment of Charging Current.")

Effect of Overdischarging.—If discharge is continued after the density of the electrolyte has fallen to 1·15 or the cell voltage to 1·7 volts, or if the cell is allowed to remain in this discharged condition, another form of lead sulphate is produced and deposited on the plates as a hard, white non-conducting substance.

Sulphation.—The formation of lead sulphate is the normal result of chemical action on discharge: it becomes injurious to the cells when deposited in the manner just referred to. Among the conditions under which this occurs are overdischarge; prolonged discharge state; insufficient charging; too infrequent charging; local action; incorrect density of electrolyte. When the deposited lead sulphate reaches this chronic state, the phenomenon is known as "sulphation." Sulphated plates feel very hard; the positive plates are pale brown or yellowish brown instead of a healthy chocolate colour; the negative plates are almost white. As this excessive sulphate is non-conducting, sulphating increases the internal resistance of the cell and so lowers the voltage and capacity on discharge; while on charge a sulphated cell may require 3 volts or more to send a current through it. This is misleading, as the observer may conclude from the high reading that the cell is fully charged. This is one reason why hydrometer readings are always preferable to voltmeter readings in cell testing. Further, owing to the excessive bulk of sulphated material,

the positive plates become buckled and the cell life shortened in consequence.

A chronically sulphated cell is useless, but this stage is reached only by sheer neglect or gross misuse.

Desulphation.—Moderate sulphation can be reduced by prolonged charging at low rates. For this purpose, use preferably water or weak acid as the electrolyte. During the process, when the electrolyte reaches a density of 1·15, it is well to replace it by pure water. On completion of the process, the plates should be immersed in electrolyte of correct density, as specified by the maker.

It is well to avoid advertised remedies for sulphated cells. Battery troubles should usually be attended to in the maker's works or service depôts.

From time to time, a deliberate overcharge is desirable to ensure that the plates are thoroughly desulphated.

Topping Up.—In addition to proper charging, a storage battery needs topping up with pure water to keep the level of the electrolyte about $\frac{1}{2}$ inch above the top of the plates. It has been explained already how water may be lost by electrolytic action in overcharging, and there may also be some loss from evaporation, especially in warm weather, or if the exhaust pipe is too near the battery.

To top up, use distilled water and clean vessels. Do not leave distilled water in an unstoppered bottle. Impure water causes local action (*i.e.*, discharge inside the battery) owing to the presence of chlorine and iron.

In some places, *e.g.*, Glasgow, tap water is satis-

factory for topping up. This, however, must not be taken as a general rule, and when any doubt exists as to the purity of the water, distilled water should be used.

Though a properly-treated battery in good condition should not require frequent topping up, it is fatal to neglect this simple precaution. If the level of the electrolyte fall below the top of the plates, the exposed portion dries out and becomes sulphated. On topping up and re-charging, this dried-out active material may fall away, thereby permanently reducing the capacity of the cell, and possibly producing internal short-circuits. Again, while there is an exposed part of the plates, the capacity of the battery is correspondingly reduced.

A *new* battery needs particular care, for it is no unusual thing for a new cell to soak up 20 per cent. of the electrolyte in the plates and separators. The topping up necessitated by this initial absorption should be done with dilute acid at the correct density. Subsequently however, water only must be used, unless some of the electrolyte is lost by spilling, etc.

As water is less dense than the electrolyte, it is useless to take the density of the electrolyte just after the battery has been topped up. Also, just after topping up, the battery should not be left in a place where the water can freeze. In cold weather, therefore, the battery should be charged after topping up. When the battery is well charged, there is practically no danger of the electrolyte freezing. The vent holes in the stoppers should be kept free from ice, as well as from dust and dirt.

Neglect of these precautions may result in a burst container.

Corrosion.—To prevent oxidation of brass or copper terminals, smear these with vaseline. Corroded surfaces should be wiped with a cloth soaked in soda or ammonia. Lead or lead-coated terminals, which are now widely used, do not corrode.

Maintenance Rules and Precautions.—To sum up, keep the battery well charged ; and, if possible, adjust the charging current to meet the demands made on the battery. Do not overcharge persistently (there is less danger of this with coil than with magneto ignition). Keep the electrolyte topped up. Keep the outside of the battery clean. Keep connections clean and tight (a loose connection may not only prevent starting, but it may cause an arc which will explode the gas). Do not hold a naked light near the battery, as it may cause an explosion.

Care of Idle Batteries.—When a battery is not to be used for a lengthy period it should be fully charged, and periodically—say, every month—be given a freshening charge. This is necessary to compensate for local action and leakage, which may discharge the battery at a rate equal to 1 to 2 per cent. of its normal rate.

In some cases it is customary to send a " trickle " charge through the cells continuously. *Example :* the 20-hour discharge current of a 50 ampere-hour battery is $50/20 = 2{\cdot}5$ amperes. A 2 per cent. trickle charge would thus be $2{\cdot}5 \times 0{\cdot}02 = 0{\cdot}05$ ampere. With this trickle charge the battery will then always be ready for service.

If the cells are to be definitely taken out of service, it is best to follow the maker's instructions. Some makers recommend charging the battery, opening the cells, swilling with water and drying the positive plates, swilling the negative plates, soaking in pure water for forty-eight hours and then drying. Other makers advocate discharging to zero, filling up with water and short-circuiting the terminals for forty-eight hours and then drying out.

When re-commissioning, treat as a new battery, allowing acid to soak for twelve hours before charging. Continue charge until density remains constant for twelve hours.

Adjustment of Charging Current.—Although car batteries under running conditions may have to absorb current up to four times the normal charging rate, and the charging dynamo may be designed to provide this current, it does not follow that these conditions are best suited to the demands on the battery. In general, manufacturers can only anticipate average needs, but the individual user can often do much to improve matters, especially where the charging current can be reduced.

Consider two extreme cases : A doctor or a tradesman, using his automobile for local work, is continually starting his engine, and therefore needs an ample battery. In such cases the charging switch will be continually closed, and the dynamo should be adjusted to give a large charging current. Even then it may be needful to give the battery an independent charge from time to time. On the other hand, consider a car with magneto ignition used solely for long runs. The battery here is

almost idle, and the charging current should be correspondingly reduced. (Means for varying the charging current will be explained in the chapter dealing with the charging generator.) By this precaution not only is overcharging avoided, but the life of the battery is lengthened owing to the easier conditions under which it works, for it is always better to charge over long periods at a low rate than over short periods at a high rate.

The lamps need not affect either case very much, because the charging switch would always be closed when the lamps were used.

Capacity of a Cell.—The capacity of a cell is measured in *ampere-hours*, denoting that the cell will give a rated current for a specified period. The normal discharge rate of a car battery is usually based on its twenty-hour rate. For example, a 50 ampere-hour cell will give $50/20 = 2{\cdot}5$ amperes continuously for twenty hours. If discharged at a greater rate than this, its ampere-hour capacity falls. For example, if a cell is discharged in one hour, it will give less than 50 per cent. of its 20 ampere-hour capacity. This is partly due to the time factor entering into the chemical changes which take place.

Capacity of a Battery.—The ampere-hour capacity of a battery depends on the way in which the cells are connected. Suppose, for example, we have six 50 ampere-hour cells. These can be joined in series, as shown in Fig. 4, to give a 12-volt, 50 ampere-hour battery. The current is 2·5 amperes with a twenty-hour rating.

On the other hand, the six cells can be grouped,

as shown in Fig. 5. We have now a 6-volt, 100-ampere-hour battery. The same result would be obtained by joining three 100-ampere-hour cells in series (see Fig. 6). In both cases the current is 5 amperes with a twenty-hour rating.

In this respect it is misleading to compare the current or ampere-hour capacities of batteries.

In order to obtain a proper comparison, the energy

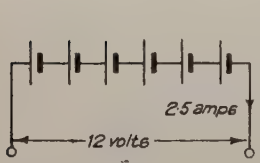

Fig. 4.

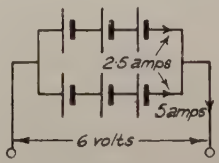

Fig. 5.

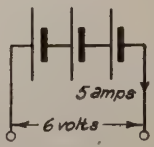

Fig. 6.

Fig. 4.—Six 50 ampere-hour cells in series, giving a 12-volt, 50 ampere-hour battery.

Fig. 5.—Parallel connection of two sets of three 50 ampere-hour cells, giving a 6-volt, 100 ampere-hour battery.

Fig. 6.—Three 100 ampere-hour cells in series, giving a 6-volt, 100 ampere-hour battery.

or watt-hour capacities must be considered. (Watts = volts × amperes.)

	Ampere-hour capacity.	Watt-hour capacity.
Fig. 4	50	$12 \times 50 = 600$
„ 5	100	$6 \times 100 = 600$
„ 6	100	$6 \times 100 = 600$

The comparison is thus definite only when the voltage as well as the current is considered.

From this it follows that a larger power output can be obtained from a 50-ampere-hour, 12-volt battery than from an 80-ampere-hour, 6-volt battery.

Effect of Temperature on Capacity of Cell.—The resistance of the electrolyte rises as the temperature falls, so that in cold weather the starting conditions are worse than in warm weather. For example, in a 12-volt battery discharging at 150 amperes, the voltage drop in the battery is affected by the temperature and state of charge roughly as follows :—

Condition of battery.	Voltage drop in battery.
Fully charged at 60° F. .	. 25 per cent.
Fully charged at 32° F. .	. 33 ,,
Half charged at 32° F. .	. 50 ,,

Comparing the effects of the first and last cases, this means that there may be a 50 per cent. higher voltage at the motor terminals in the former than in the latter case. Since the current is proportional to the voltage, it is clear that with the lower voltage the current may be insufficient to enable the motor to move the engine ; whereas with the higher, starting may be quite easy. This example should make clear the importance of keeping the battery well charged.

Battery Faults.—A battery that exhibits a persistently discharged state indicates the existence of a fault, either in the battery itself or in the outside circuit. In this chapter the battery only will be considered, outside faults being discussed elsewhere. Beyond the satisfaction of locating a battery fault, there is little to be gained from the investigation of such cases, for the remedy of such faults is usually a matter for the battery maker.

Before attempting any tests, a visual inspection

should be made for anything so obvious as dirt, water, loose wires, etc. For the tests a hydrometer and a 3-volt voltmeter are needed. To determine the condition of a battery that has failed, it is advisable to see that each cell is filled with fresh acid of the correct specific gravity and to give it a full charge at normal rate. The voltage of all the cells should rise at about the same rate and at the end of the charging period should be about 2·6 volts *while the charging current is flowing.* The specific gravity of each cell should be taken immediately after switching off and compared with the figure given by the makers.

Defective cells are indicated when near end of charge by :—

(*a*) *Low Voltage.*—This may be due to internal short-circuit, and should be checked by taking specific gravity, which will also be lower than the other cells. Short-circuit may be due to collection of sludge ; if so, wash cell out with dilute acid.

(*b*) *Voltage much Higher than the other Cells.*—Probably due to large internal resistance caused by sulphating, broken plates, or connection to lugs. Excessive gassing may indicate this condition.

On discharging, a defective cell will be revealed by its lower voltage measured while current is flowing.

Battery Earthed.—When cells are in position on the car, *test for earth* by removing connections and testing between each terminal and earth with voltmeter. A reading on voltmeter indicates an earth or leakage fault which may account for the run-down condition of the battery. If possible test each cell independently.

Rough Test for Faults.—Disconnect battery wire and touch the battery terminal lightly with it when all switches are off. A spark indicates a fault, which may be an earth or short-circuit in wiring or an earth in battery (see also Chapter VI.).

Tests for Polarity.—When a battery is charged from an outside source—which must, of course, be direct current or rectified alternating current—there may be some doubt as to which terminal is positive and which is negative. Any of the following methods can be used to determine the polarity of a source of direct current :—

(1) Lay the two terminals $\frac{1}{2}$ inch apart on damp pole-finding (litmus) paper laid on wood. The end which turns red is negative.

(2) Pass a current through dilute acid, when gas is given off more rapidly at the negative pole.

(3) Lamps in series with battery are dimmed when connections are correct for charging.

(4) Use moving-coil voltmeter on which the positive terminal is marked.

It is essential for charging that the positive pole of the charging supply (generator or battery or supply mains) be connected to the positive terminal of the battery.

Tests for State of Battery Charge :—(1) A rough test of the state of charge of the battery is to switch on all the lamps. Bright, white filaments denote a fully charged, reddish filaments denote a fully discharged battery. A rapid falling off in light denotes an exhausted battery, or possibly an earth fault.

(2) A more severe test is to use an instrument consisting of a short length of resistance metal and

a voltmeter. The two ends of the resistance metal are placed across the cell terminals and the reading on the voltmeter noted. The resistance is so designed that the voltmeter reads approximately 1 volt when the cell is fully charged. This test is pretty severe, and the current should not be allowed to flow longer than is necessary for the reading to be taken.

CHAPTER II

THE ACTION OF ELECTRICAL MACHINES

The subject-matter in this chapter applies not only to the starting motor, but in an equal degree to the charging generator and also in a great measure to the magneto.

The Fundamental Principles of Electrical Machines.—Two principles underlie the action of the electric generator and the electric motor :—

(1) A coil carrying an electric current and lying in a magnetic field is acted upon by a mechanical force.

(2) If there is relative movement between a coil and a magnetic field an electromotive force (or voltage) is induced in the coil.

These principles are illustrated in Fig. 7, where a coil, capable of revolving about *O*, is represented as it exists in an actual machine. There are two ways in which these fundamental principles may become apparent to us : (1) in the electric motor ; (2) in the electric generator.

(1) **The Electric Motor.**—When the force, due to the interaction between the magnetic field and the coil carrying the current, causes the coil to move in the direction of the arrows marked "force," mechanical work is done and at the same time the electromotive force induced by the motion of the coil opposes the current. In order to maintain the current, therefore, an external source of electric

energy is needed, such as a battery or supply mains. Now the product of the current and the applied voltage required to overcome the induced electromotive force represents the electric power supplied to the coil; while the product of the force and the velocity of the coil represents the mechanical power supplied by the coil. The name given to a machine which converts electrical energy into mechanical

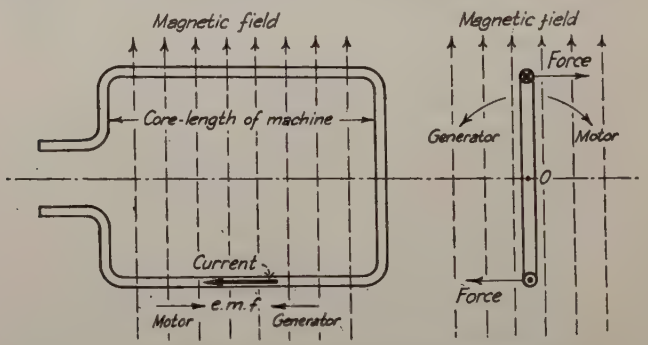

FIG. 7.—The action of the electric motor and the electric generator.

energy is "an electric motor." Here then is the principle of the starting motor.

(2) **The Electric Generator.**—If instead of allowing the force due to the interaction between the magnetic field and current to move the coil, we couple up or belt the coil to an engine and drive it against the force, clearly mechanical work must be supplied. Now reversing the direction of rotation of the coil also reverses the direction of the electromotive force induced by the relative motion between the coil and the field. Hence, instead of opposing the current in the coil the induced electromotive

force now produces the current. Here then is a machine in which the mechanical power of the engine is converted into electrical power, represented by the product of the induced voltage and the current it causes to flow in a circuit placed across the terminals. Such a machine is called an "electric generator (or dynamo)." This is the principle of the car dynamo, and it is also embodied in the magneto.

It is clearly seen, therefore, that in principle there is no difference between the electric motor and the electric generator; they are interchangeable. If the working conditions are such that the induced e.m.f. opposes the current, the machine is an electric motor; if the induced e.m.f. produces the current, the machine is an electric generator. Perhaps the reader has already thought of the "dynamotor" in this connection.

Before leaving this subject it should be mentioned that the magnitude of the mechanical force due to the interaction between the field and the current is proportional to the product of the current, the field density, the number of conductors in which the current flows and the length of the conductors lying in the field (or the "core-length").

The value of the induced electromotive force is proportional to the rate of change of the magnetic lines linking the coil (or coils), or, more simply stated, to the product of the speed of rotation and the number of magnetic lines linking the coil (or coils). Briefly, then, the induced electromotive force is proportional to the product of the speed and the field.

CHAPTER III

THE STARTING MOTOR

The Motor-Battery Starting System.—This system of starting consists essentially of a storage battery and a starting motor.

When starting the engine the motor is usually geared to the fly-wheel by the aid of an automatic device. In one well-known type the pinion is not fixed on the motor shaft, but moves along a screw. Thus, when the motor is started, the loose pinion at first, owing to its inertia, revolves more slowly than the shaft, and in consequence it acquires a translatory motion along the screw. This brings it into mesh with the teeth on the fly-wheel, and so causes the engine to revolve. As soon as the engine reaches a speed at which a spark fires the explosive mixture, the engine acts under its own power and increases its speed. This increased speed of the fly-wheel automatically causes the pinion to fly back along the screw, thereby disengaging the gears. When this occurs the motor is heard to race, and the starting switch should be opened forthwith.

According to the conditions this starting operation may take one to five seconds, or even longer when a few revolutions are necessary to get the requisite mixture into the cylinders. If the engine refuses to move, the switch should be released at once, for in

this state the battery is short-circuited ; perhaps the gear lever has not been left in neutral, and the hand brake may have been left on in addition.

Torque.—The term " torque " is used to denote the turning moment or effort of the motor or engine, as the case may be. On the one hand, there is the *driving* torque, which is developed by the motor or engine and which causes the motion ; on the other hand, there is the *resisting* torque of the engine and mechanism which opposes the motion. The resisting torque of the engine is familiar to every one who has cranked an engine. When the driving torque exceeds the resisting torque the speed increases until the latter torque equals the former ; conversely, when the resisting torque is greater than the driving torque the speed falls until these again become equal. For example, when the accelerator pedal is depressed to increase the speed of an automobile, acceleration occurs until the resisting force offered by the road, the wind, the gradient and the mechanism combined equals the driving force exerted by the engine. When this happens a steady speed is reached. The reader should clearly understand the mechanics of motion : acceleration, retardation, centrifugal force, braking are important in motor vehicle working.

Starting Torque.—The driving torque exerted by a motor at starting is known as the starting torque. If the starting torque of the motor is less than the resisting torque of the engine, the latter will not move. If it is greater the engine will commence to revolve and the difference between the driving and the resisting torque will be utilised in accelerating the

engine. Assuming for the moment that the ignition spark is cut off, the engine speed will continue to increase until its resisting torque equals the driving torque of the motor, at which stage steady conditions are attained.

Whether the engine will begin to run under its own power when the ignition is switched on and everything is in order, depends on whether the starting set is suitable for starting the engine.

Conditions at Starting.—The starting motor must rotate the engine at such a speed that it can work under its own power. The conditions under which an engine has to start should be understood, for a properly-designed starting set may be quite useless unless everything connected with the engine, motor and battery is in order. Although a self-starter must start the engine under the most adverse conditions, it is essential that the whole equipment is working properly.

For example, the carburetter must be correctly set to give the proper mixture. There must not be air leaks at the inlet valves, nor troubles arising from pitted valves and seats, nor from wrongly-adjusted tappets or other devices. The engine compression must not be faulty, due to slack piston rings. The ignition system must be in order—a magneto in which the magnets have become weak cannot be expected to give the necessary spark at starting. The contact breaker on magneto or coil, whichever system be used, must be in order. The sparking plugs must be sound, clean and correctly set. The motor brushes must make proper contact on the commutator. The battery must be ade-

quately charged. The starting circuit must be free from loose contacts. In brief, everything mechanical and everything electrical must be properly maintained.

The battery has to bear the brunt of the shock at starting. At the instant the starting switch is closed the battery is short-circuited and remains so as long as the engine is at rest. When thus short-circuited the battery current in a 12-volt system may rise to 200 amperes or more, while the normal current may be only about 10 amperes. The current falls and the voltage rises rapidly as soon as the motor begins to accelerate. If everything is at a temperature about or below the freezing point of water, a few seconds may well be needed to bring the engine to a speed at which it will work under its own power. An engine at, say, 32° F., may require a turning effort three times as great as when the same engine is warm. With magneto ignition, engines usually fire at speeds between 80 and 130 r.p.m. ; with coil ignition, half this speed may suffice if the battery is well charged. It must be remembered, however, that firing may not occur during the first few revolutions.

Ignition conditions are also worse when the mixture in the cylinder is cold. The voltage needed to send a spark across the sparking plug electrodes depends on the density of the gas, and at constant pressure the density of a gas varies inversely as the absolute temperature. In consequence, when starting cold the requisite sparking voltage may be as high as 7,000 volts ; whereas after running, *i.e.*, when the engine is hot, a voltage of 4,000 may suffice.

Thus, when starting cold with magneto ignition an engine has to attain a higher speed before it gets away than when hot. Even with coil ignition, sparking conditions may be adversely affected by the fall in battery voltage when the starting motor is in circuit, necessitating a higher engine speed with its correspondingly higher battery voltage. This effect would be most pronounced with a poorly-charged battery.

The battery itself is also at a disadvantage when

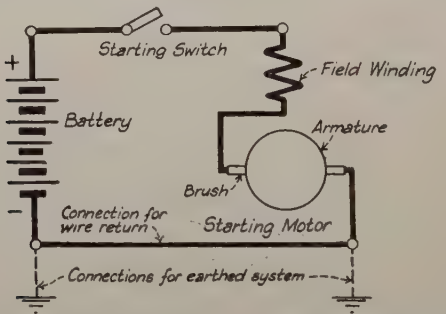

Fig. 8.—Connection diagram for starting motor and battery.

cold, owing to its higher internal resistance—an electrolyte in this respect being unlike a metal.

Nevertheless, the starting motor must yield sufficient torque to turn the engine under all adverse conditions, such as coldness, strong compression, thick oil, stiffness after long periods of standing, excessive moisture, etc., and to drive it at a speed sufficient to produce adequate fuel evaporation and a spark which will fire the fuel.

The Starting Circuit.—The electric circuit of the starting system is controlled by a switch and is

arranged to exclude the ammeter. The switch may be operated by hand or by foot. It should be borne in mind that this switch has to carry a large current, and it should therefore be closed firmly, otherwise the contacts will soon become pitted and troublesome starting may easily result. The connection diagram for the battery, the motor, the switch and the wiring, is shown in Fig. 8.

Series Motor and its Characteristics.—The motor used for starting the engine is called a " series " motor, because the field winding is in series with the armature winding, so that the same current passes through both. In this motor, therefore, the main current is also the exciting or magnetising current (Fig. 8). The speed and torque characteristics with this connection are ideal for a starting motor.

It has already been mentioned that the induced electromotive force is proportional to the product of the speed and the field. Consequently, for a given strength of field the speed varies directly as the induced electromotive force. This can be written :—

$$\text{Speed of motor} = \text{constant} \times \frac{\text{induced e.m.f.}}{\text{field}}$$

$$= \text{constant} \times \frac{\text{battery voltage} - \text{voltage drop}}{\text{field}}$$

The battery voltage is usually 6 or 12 volts, but there is a large drop in voltage during starting. The voltage drop represents what is lost in resistance in the battery, motor, switch and circuit, as already explained in the chapter on batteries. If the numerator " battery voltage — voltage drop " remained constant, then the speed would vary

inversely as the field. Actually at low speeds the voltage drop has a very adverse effect.

(*a*) *The Magnetisation Curve.*—In the series motor the field is produced by the motor current. The relation between the field and current is shown in Fig. 9, and is known as the magnetisation curve. This is the fundamental characteristic of the motor, on which the other properties depend.

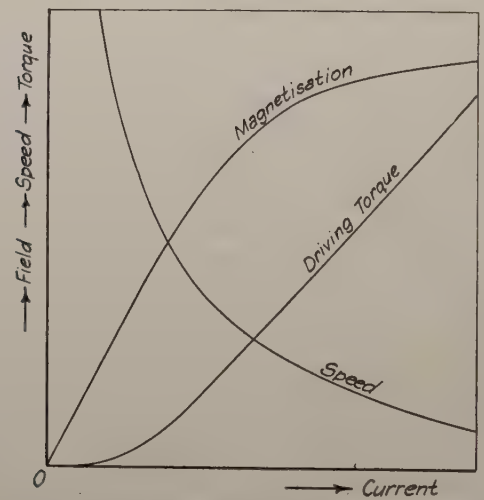

Fig. 9.—Characteristic curves of series motor.

(*b*) *The Speed Curve.*—This characteristic is also shown in this figure.

It will be noticed how the speed rises as the current falls, and that at low speeds the current is very large. When the engine fires and the pinion is disengaged, the motor speed may reach an excessive

value, and for this reason the switch should be released immediately starting is effected.

(*c*) *The Driving Torque Curve.*—It has been mentioned that the torque developed in a motor is proportional to the product of the current and the field, that is, driving torque = constant × current × field. This is also shown in Fig. 9. With a large motor current a large torque is developed, and this is seen to fall off as the current falls and the speed rises.

(*d*) *The Speed-Torque Curve.*—From Fig. 9 we can plot the speed as a function of the torque. The curve shown in Fig. 10 is taken with a starting motor working off its own battery. From this curve we learn that with a given motor there is a definite speed corresponding to each value of torque. The corresponding voltage and current curves are also given. Naturally these characteristics of the motor in question would not necessarily be the same with a different make or size of battery than that used, nor would the same result be obtained with the battery at 70° F. as with the battery at 40° F., nor with the battery half charged as with the battery fully charged.

Consider the speed-torque curve for a moment. The resisting torque of the engine is largely affected by the temperature. With the engine cold the driving torque of the motor may only suffice to bring the speed of the engine up to the point marked "cold" in Fig. 10. On the other hand, when the engine is at normal temperature or warm, the higher points marked on the speed-torque curve will be reached.

With a given set of conditions it is beyond the user's power to alter the result. Suppose, for

example, with the engine cold the speed imparted to it by the motor is 90 r.p.m., and that the magneto used requires a speed of 100 r.p.m. in order to produce a spark sufficient to explode the mixture. This means that the engine cannot be started when cold by the starting system provided, though no troubles may be experienced when the engine is warm. With another magneto or with coil ignition, of course, starting when cold may be quite satisfactory.

From this illustration it is clear that both battery and motor must be designed to meet the required conditions. Either or both may be too small for the service required of them. It is a simple matter to determine whether the battery is at fault. Obtain a fully-charged battery of larger capacity—which need not be mounted on the vehicle—and provisionally replace the original battery. If the engine now starts the remedy is obvious. If starting is not effected, a larger starting motor or a different gear ratio is indicated. This is not so simple to alter, but there may be no alternative. Occasionally a larger motor is the sole remedy.

Current during Starting.—The current curve in in Fig. 10 is also instructive. With the engine at rest, the current rises to its short-circuit value, no matter whether the engine is cold or hot. In the latter case, however, the strain on the battery is much less than in the former, because the engine speeds up much more rapidly and the current falls quickly to a low value.

The worst condition clearly exists when the engine is cold, for not only is a large current then

required, but a certain number of revolutions are needful in order to obtain the proper mixture in the cylinders. Consequently the battery has to give a large current for a relatively long period. Nevertheless, it is less severe for the battery to keep the starting switch closed a little longer and obtain a sure start than to make two or three unsuccessful

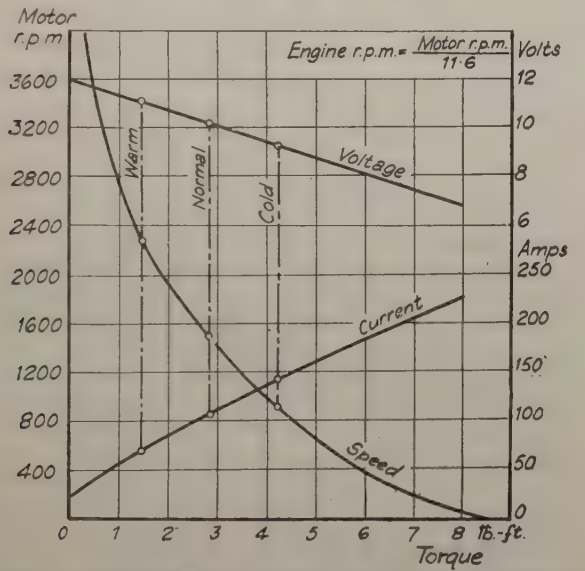

FIG. 10.—Performance curves of a 12-volt starter motor operated from a car battery.

attempts in rapid succession. In any case, a pause should be made between successive attempts to enable the battery to recover its voltage. Cases, of course, differ. For example, it may be found necessary to draw in a quantity of explosive mixture and wait a short time to let the cold petrol spray

volatilise—equivalent to priming the cylinders—and then to give the engine another spin with the magneto in action. Whatever method is adopted, however, the less often the starter motor is used the longer the life of the battery. From this it must not be inferred that we are advocating cranking the engine by hand to spare the battery. A properly-designed battery is intended to start the engine under all conditions and should be called upon to do so. The only point we wish to emphasise is that the starting switch should not be used needlessly.

Effect of Voltage Drop.—The fall in the voltage curve in Fig. 10 is mainly due to the internal resistance of the battery. The lower the temperature the larger the loss of volts in the battery. This cannot be avoided. Also the more discharged the battery the greater the voltage drop ; this is avoidable.

In addition to the drop in the battery, however, the resistance of the remainder of the circuit may be important. Not only must there be no loose contacts, or rough switch surfaces, but the cross-section of the cables must be adequate and the motor brushes and leads must be in order.

Effect of Size of Motor.—The size of motor has the chief influence on starting conditions. Although a larger battery and large cables will help somewhat, they cannot be expected to compensate for a motor that is too small. Hence, if the engine will not start with these aids, a larger motor or a different gear ratio is called for.

A large motor capable of producing a certain start with the first trial taxes the battery far less than a small motor with repeated attempts.

Comparison between 6-Volt and 12-Volt Starting Systems.—It is well to understand the conditions under which the speed attained by the engine shall be the same with a 6-volt system as with a 12-volt system.

These conditions are :—

(1) The motors must give the same torque at the same speed. For this purpose the current at 6 volts must be twice that at 12 volts when the field is made the same in both cases and the number of conductors in the armature of the 6-volt motor is half that in the armature of the 12-volt motor.

(2) The percentage voltage drop must be the same in both cases. To obtain this, the ampere-hour capacity of the 6-volt battery must be twice that of the 12-volt battery, the cross-section of the cables and of the total armature path with 6 volts must be four times that with 12 volts ; also the percentage contact drop under the brushes must be the same in both cases.

The last condition is the hardest to satisfy, because, owing to the properties of the carbon brush, there will be practically the same contact drop at the brushes in each case. In general it may be reckoned that there is a drop of 0·5 volt under each brush ; consequently the loss of $2 \times 0{\cdot}5 = 1$ volt is much more serious in the 6- than in the 12-volt system.

Ignoring the effect of brush contact drop, however, it follows that if the conditions under (1) and (2) have been satisfied, then there is no difference between the 6- and 12-volt systems as regards starting. In some cases where a given engine is found to start with a 12-volt system and not with

a 6-volt system, the failure of the latter is due, not so much to the large percentage drop under the brushes, but to the non-fulfilment of some of the other conditions detailed under (1) and (2).

Commutator Brushes for Starting Motor.—The motor, like the battery, can only withstand the severe conditions at starting for a very brief period, but it has been found feasible to design starting systems for such intermittent work. The commutator brushes illustrate this admirably. Normally current densities under the brushes do not exceed 50 to 100 amperes per square inch. Here the rating is increased some tenfold. For example, the commutator brush on a starting motor taking 200 amperes on switching in measured $\frac{5}{8}$ by $\frac{1}{4}$ inch, giving a current density as high as $\frac{200}{\frac{5}{8} \times \frac{1}{4}} = 1{,}280$ amperes per square inch. Such enormous values are only permissible instantaneously, and they decrease rapidly as the motor speed increases. For this purpose highly metallic brushes with 5 to 25 per cent. of graphite are employed, giving a contact drop of 0·3 to 0·5 volt per brush. It is safer to assume the higher value for practical conditions.

It has been seen that it is important to keep this value as low as possible, particularly in 6-volt systems. The means employed for reducing the voltage drop under the brushes consist of carefully bedding the brushes and pressing them firmly on to the commutator. The brushes are bedded in position by working a piece of carborundum cloth to and fro until the curvature of the brush is the same as that of the commutator, while the brush springs are

adjusted to exert a pressure of about 4 to 5 lb. per square inch, or twice the pressure employed for ordinary commutator brushes.

Care must be taken to ensure smooth working of the brushes in the holders and of the brush levers in their pivots ; contacts must be tight ; flexibles should be used for leading the current from the cables to the brushes. Brush springs sometimes lose their temper. Neglect of any of these precautions may render starting difficult. Moisture and dirt must also be kept away from the interior of the starting motor.

Starting Troubles.—Some of the chief troubles connected with motor-battery starting systems and their possible causes are summarised below :—

Trouble	Possible Cause
Motor will not run or not run fast enough.	Discharged battery.
	Bad connections at battery, switch or motor.
	Brushes wrongly adjusted.
	Engine locked.
Pinion does not engage.	Screw shaft dirty or bent.
	Thick oil on shaft.
Pinion does not disengage after engine fires.	Screw shaft dirty or bent.
	Pull-back spring too weak.
	Pinion sticking due to wear in keys or threads.
Bad sparking at brushes.	Spring pressure too low.
	Brushes sticking in holders.
	Dirty commutator.
	High micas in commutator.
	Bent screw shaft.
Motor takes large current and only crawls.	Short-circuit fault in field coils.
	Armature coils burnt out.
Motor takes only small current.	Bad or broken connections of armature coils to commutator, or in circuit.

CHAPTER IV

THE THREE-BRUSH GENERATOR AND THE AUTOMATIC CUT-OUT

The Three-Brush Generator

In order to charge the battery or light the lamps, a direct voltage which is practically constant is needed. The electromotive force induced in an electrical machine is proportional to the product of the magnetic field and the speed at which the machine rotates. In a motor vehicle, where the dynamo is driven by the engine, the engine speed varies over a wide range ; consequently, to obtain a constant voltage, the field must vary inversely as the speed—as the speed of the engine increases, the value of the field must automatically decrease in the same proportion, and conversely. This condition is hard to satisfy ; in practice, therefore, a compromise is essential. There are various ways of regulating the generator voltage to compensate for speed variations—some complicated, others simple. The device we shall consider here is the common one known as the " three-brush dynamo (or generator)," working in conjunction with a storage battery.

Since the three-brush machine is a modification of the ordinary shunt generator, the latter will first be considered.

The Shunt Generator.—In the common shunt generator the field winding is in parallel with the armature winding and the load, that is, the field winding is *shunted* across the armature (Fig. 11). By placing a regulating resistance (field rheostat) in series with the field winding the exciting current can be varied at will. Ignoring secondary effects, if the exciting current and the speed are kept constant, the induced electromotive force will remain constant.

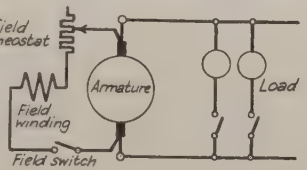

FIG. 11.—Shunt generator.

Effect of Varying Speed of Shunt Generator.—If the exciting current is kept constant (either by adjusting the field regulator or by exciting from an external source) while the speed is varied, the induced electromotive force is then directly proportional to the speed (see curve, "constant field," in Fig. 12). If, however, the resistance in the exciting circuit remains constant and the terminals are connected to the armature brushes, then, so long as the magnetic field is directly proportional to the exciting current, the voltage will vary as the square of the speed. Beyond this the rate of increase of terminal voltage will be less rapid, and when the magnetic circuit becomes saturated the voltage again becomes directly pro-

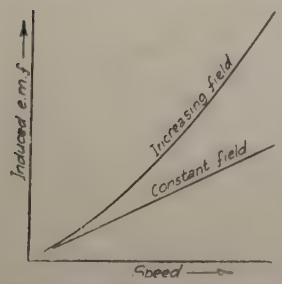

FIG. 12.—Effect of speed on induced electromotive force in shunt generator.

portional to the speed. This is shown by the curve "increasing field" in Fig. 12. It is at once clear that neither of the above arrangements is suitable for the automobile. Thus a simple shunt machine will not solve the problem.

We need some device whereby the field falls off as the speed rises, and conversely. In order to understand the solution we must examine certain properties of direct-current machines.

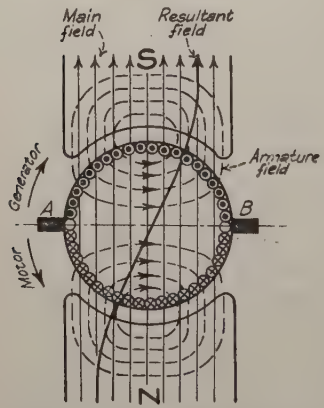

FIG. 13.—Magnetic fields in a direct-current machine.

Armature Reaction in a Direct-Current Machine.—Whenever a current flows through a winding a magnetic field is produced. The exciting current, flowing through the exciting windirg, produces what is known as the main field. Similarly the armature current, flowing in the armature winding, produces the armature field. These are represented in the cross-section of a bipolar machine shown in Fig. 13, and in the developed diagrams in Fig. 14. With the brushes AB fixed in the geometrical neutral zone, as shown, the axes of these two fields are at right angles to one another.

Now two magnetic fields cannot have a separate existence in the same space at the same time; consequently they combine to form a resultant

field, also shown in Fig. 14. It is thus seen that at no-load (armature current = zero) the distribution of the field in the air gap is symmetrical, but on load it is distorted by the armature field (see Fig. 14). This effect is known as *armature reaction.*

Potential Curve of Commutator.—We have now to

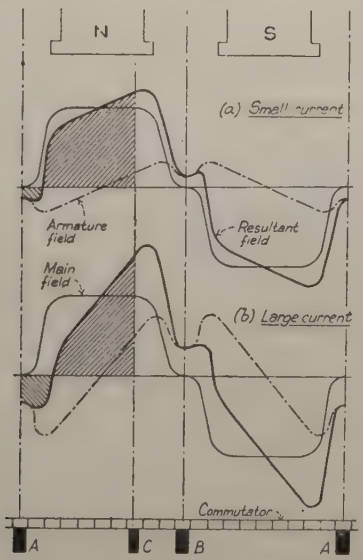

FIG. 14.—Magnetic field distribution in a direct-current machine.

consider how the voltage depends on the brush position. Suppose one brush to be fixed in the geometrical neutral zone A, and another brush, C, to be moved slowly from A to the other geometrical neutral zone B, with a voltmeter connected between A and C. The voltage will then gradually increase in proportion to the shaded area in Fig. 15, which is

drawn for the no-load condition. Thus as the brush C moves from A to B the voltage between A and C increases from zero to its maximum value, and is equal to V in the position shown. The voltage curve thus traced out is known as the *potential curve of the commutator*, since it represents

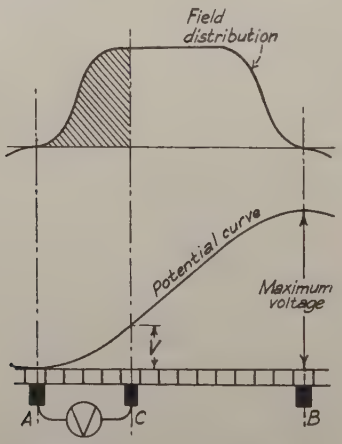

Fig. 15.—Potential curve of commutator at no-load (constant speed assumed).

the distribution of the voltage or potential over the commutator.

Thus the voltage between two brushes placed anywhere on the commutator is represented by the vertical distance between the two respective points on the potential curve.

The same applies to the machine when loaded, except that the potential curve is obtained from the resultant field distribution. Corresponding to every load there will thus be a definite potential

curve. In Fig. 16 the potential curves are shown for the cases of the two values of armature current in Fig. 14. The brushes A and B, fixed in the geometrical neutral zone, are called the main brushes, and the voltage between them is shown in Fig. 16 as main volts between A and B.

Effect of a Third Brush.—In addition to the main brushes A and B let a third brush, C, be placed on

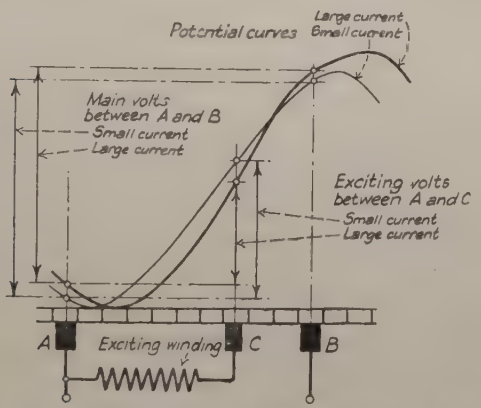

FIG. 16.—Potential curves of commutator at the two loads in Fig. 14 (constant speed assumed).

the commutator, as shown in Figs. 14 and 16. The *voltage* between the brushes A and C is then *proportional to the shaded area* in each case. We shall call A and C the exciting brushes. An inspection of Fig. 16 shows that with speed and main field constant the voltage between the exciting brushes AC falls off rapidly as the current increases. The explanation is that armature reaction makes itself felt much more in the region of the brush C than in

the geometrical neutral zones A and B. This fact leads to a partial solution of the problem of obtaining a constant voltage at a varying speed.

The Three-Brush Generator.—This is a shunt machine with the addition of a third brush ; that is, in addition to the main brushes, there is a third or exciting brush (Fig. 17). The load (lamps, etc.) is placed across the main brushes, and the field winding is connected to the exciting brush and a main brush. The shunt regulator is dispensed with.

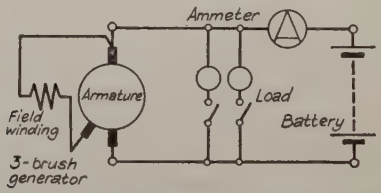

Fig. 17.—Connections of three-brush generator and battery.

If the generator is run at a constant speed and the load gradually increased, we get the falling voltage characteristic marked "generator characteristic" in Fig. 18.* Though this is a step in the right direction, the voltage will not remain sufficiently constant as the engine speed rises and falls. To complete the solution, a storage battery is needed.

Action of Three-Brush Generator and Battery in Parallel.—The generator and battery are joined in parallel as shown in Fig. 17, and the load is placed across the common bus-bars or terminals. In Fig. 18 the generator characteristic curve is shown to the

* This curve was taken on a 3-brush car dynamo, and includes the effect of the exciting current on the armature reaction.

right of the vertical axis, while the battery characteristic, that is, the battery voltage at different charge and discharge currents, crosses this axis. Linked up in this way, the generator voltage is anchored to the battery voltage. Not only have the generator and the battery always a common terminal voltage,

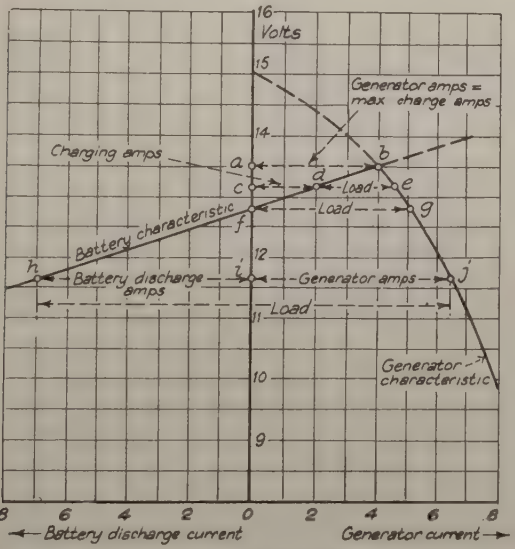

Fig. 18.—Parallel working of three-brush generator and battery (constant speed assumed).

but this common voltage is kept fairly constant by the battery independent of the engine speed. Taking the constant-speed characteristic in Fig. 18, let us examine the action. It will be seen that any current measured between the vertical axis and the generator characteristic will denote the current given by the generator ; while any current measured

between the vertical axis and the battery characteristic will denote the battery current—a charging current being to the right and a discharging current to the left. The horizontal distance between the two characteristics represents the external load current, *e.g.*, lamps.

At *a* the voltage is 13·5, the external load is zero, and the whole generator current *ab* is the charging current of the battery. At *c*, where the generator current is *ce*, the voltage has fallen to 13·2 due to a load *de*, the part *cd* representing the battery-charging current. When the load is further increased to *fg*, the voltage falls to 12·8 where the battery characteristic crosses the axis. The whole generator current *fg* is now taken by the load. In this case the battery merely "floats" on the bus-bars.

Increasing the load still further to *hj*, the voltage now becomes 11·7. Part of the load *ij* is supplied by the generator, and part *hi* by the battery, which is now being discharged.

It is thus seen that the combination of the battery and generator gives practically what is needed, while the system has the merit of utilising and charging the battery which is needed for the starting motor.

Before considering the means for automatically regulating this combination—viz., the cut-out—there are certain characteristics to be considered.

Setting of Third Brush.—By varying the position of the third or exciting brush it is possible to obtain a certain amount of regulation of the generator current without affecting the voltage very appreci-

ably. For example, a 12-volt generator may be designed to give 8 amperes with an exciting voltage of 9 volts. By rocking the third brush back by about a commutator segment, the current can be halved; while by shifting it forward somewhat, the current can be increased. Provided the brush is not rocked too far forward, both voltage and current remain fairly constant for each setting over the whole speed range. This is illustrated in Fig. 19.

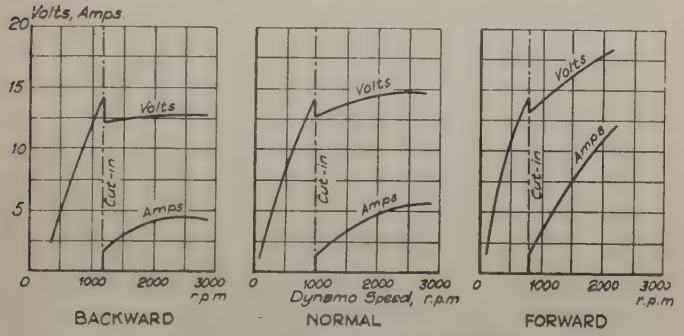

Fig. 19.—Effect of third-brush setting.

To be able to vary the charging current in this way is useful. In cases where the calls on the battery are infrequent it is well to set the third brush back. This not only prevents excessive overcharging, but the smaller current is better both for the battery and the dynamo. Both these appliances are rated fairly highly in automobile work, and anything that reduces the demand made on them is an advantage.

It is not always practicable to obtain an appreciable increase in output by rocking the third brush

forward, although something may be done to assist in keeping the battery charged on a vehicle that has to be repeatedly started, such as a delivery van.

Effect of Battery Voltage.—A cell voltage varies from about 1·8 volts when supplying current to 2·7 volts just before charging is completed. Thus to complete the charge of a 12-volt battery $2{\cdot}7 \times 6 = 16{\cdot}2$ volts will be needed. For this reason the lamps must be able to withstand a certain voltage variation.

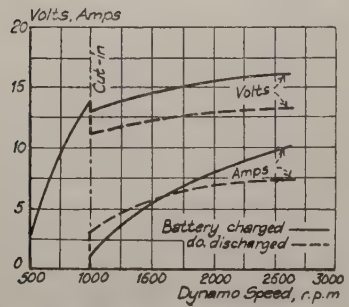

FIG. 20.—Effect of state of battery charge on terminal voltage.

The effect of the state of charge on the voltage and charging current taken from a three-brush dynamo is shown in Fig. 20. It is seen that the current is higher when the battery is charged than when it is discharged. This is the opposite of what is required, but it must be accepted as part of the compromise entailed by this method.

Another point must be remembered. It is the battery which fixes the voltage; consequently it is not permissible to use the generator without the battery. If the battery is disconnected, the dynamo voltage will rise to an excessive value and endanger both lamps and field winding. It follows that there must not be any switch in the circuit which would isolate the battery from the bus-bars.

Commutator Brushes for Generators.—The brushes for automobile generators are worked at densities

from 45 to 75 amperes per square inch, the average being about 60 amperes per square inch. For these rather high densities it is found that electrographitic or natural graphite brushes are sometimes more suitable than carbon brushes, but conditions vary greatly with different machines and mountings. A large brush pressure—4 to 5 lb. per square inch—is employed to prevent the brush leaving the commutator and to reduce the contact voltage drop, which is about 0·8 to 0·9 volt per brush. The smaller electric heating under the brush thus obtained, however, is largely offset by the enhanced heating due to friction. Care must be taken to bed the brushes properly, and to see that they work smoothly in their holders. Loose contacts must be avoided, and the flexibles must be kept clear of earthed metal. (See also p. 36.)

Owing to the smaller current the exciting brush can be made narrower and harder than the main brushes. This is desirable in order to reduce sparking, because the exciting brush stands in a strong magnetic field, which makes commutation difficult.

Power Taken by Three-Brush Generator.—In order to gain an idea of the power taken to drive the dynamo, we can consider a 12-volt machine giving a charging current of 8 amperes. Taking 15 volts as the terminal voltage towards the end of charge, the useful output $= 15 \times 8 = 120$ watts.

The efficiency can be taken as 50 per cent., so that the input will be $120/0{\cdot}5 = 240$ watts $= \frac{1}{3}$ h.p. This will enable the reader to see approximately the demand made on the engine by the charging dynamo.

If the output of the generator is reduced the input falls, but not in proportion. Nevertheless, the smaller output and the somewhat reduced exciting current will produce less heating in both armature and field windings.

Generator Troubles.—Some of the chief generator troubles and their possible causes are summarised below :—

Trouble	Possible Cause
Charging current too small.	Brush pressure too feeble. Carbon sticking in holder. Carbons badly worn. Commutator dirty or oily.
Sparking at the brushes.	Brush pressure too small. Faulty brush contact. Dirty commutator. Commutator not mechanically true.
Refusal to excite.	Faulty brush contact. Dirty commutator. Field winding broken. Armature winding broken. Armature winding earthed.
Large current pulsations (violent swinging of ammeter needle).	Dirty commutator. Faulty brush contact. Dynamo belt slipping. Loose contacts in outside circuit. Short-circuit beyond cut-out. (This reduces voltage to zero and opens cut-out. Generator then excites again and closes cut-out. This goes on repeating itself.)
Exciting winding or lamps burn out.	Battery disconnected.

The Automatic Cut-out
(or Reverse-current Relay)

When a direct-current generator and a battery work in parallel it is usual to employ an automatic cut-out (or reverse-current relay), the function of which is to switch the generator into circuit as soon as its voltage rises to a predetermined value, and to cut out the generator as soon as its voltage falls to a predetermined value. The switching in is effected by means of a voltage coil, while the cutting out is achieved by a reverse (or discharge) current flowing from the battery through a current coil.

Principle of the Reverse-Current Relay.—On a soft-iron or in some cases on a polarised core two coils are wound : the one, with fine wire which is connected across the generator terminals, is called the *voltage* or *shunt* coil ; the other, with thick wire and joined in series with the generator and the battery, is called the *current* or *series* coil. Except for a small air-gap an iron path is provided for the magnetic field of the relay, as shown in Fig. 21. The upper part of the magnetic circuit is made in the form of a light movable arm with a contact at one end and hinged at the other. A spring is arranged to raise this arm so that, when the core is unexcited, the movable contact on the arm is kept away from a stationary contact. With the contacts apart the circuit is open ; with the contacts together the circuit is closed.

When the generator field switch is closed, the revolving armature produces a voltage at the generator terminals. This sends a current through

the voltage coil, which produces a magnetic field in the reverse-current relay. As the speed rises the current increases and also the magnetic pull on the movable arm of the cut-out, as shown in Fig. 22, until the tension of the spring is overcome and the contacts close. In a 12-volt system this may occur at about 12·2 volts.

The closing of the contacts connects the dynamo to the battery, and a further increase in speed has but little effect on the terminal voltage because

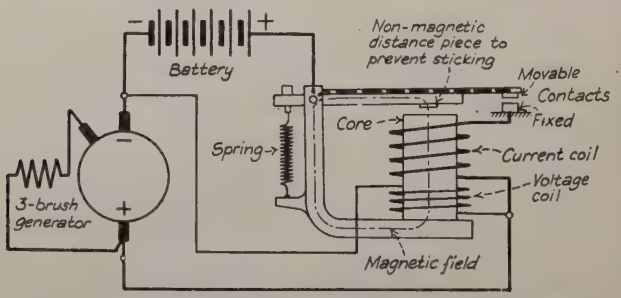

FIG. 21.—Elements of automatic cut-out or reverse-current relay.

this is now controlled by the battery, as explained in the sections on the three-brush dynamo. Instead, a charging current flows into the battery. This charging current flows through the current coil of the relay, and the ampere-turns produced by it create a magnetic field in the same direction as those produced by the voltage coil. As a result, the pull on the armature is increased and the contacts are closed more tightly by the action of a charging current coil flowing in the series coil.

When, however, the speed falls to such a value

that the generator induced electromotive force is below the battery voltage, then the current reverses and a discharge current flows from the battery through the dynamo. The discharge current being in the reverse direction to the charging current, its magnetic effect opposes that of the current in the voltage coil. This demagnetising action on the relay decreases the pull on the movable arm and allows the spring to open the contacts. The spring is adjusted to act when the current reaches about 0·5 ampere ; that is, when the contacts first close, the charging current immediately rises to 0·5 ampere ; while the contacts open when the discharge current reaches 0·5 ampere. It is usual to insert a piece of non-magnetic material between the movable arm and the core to prevent sticking.

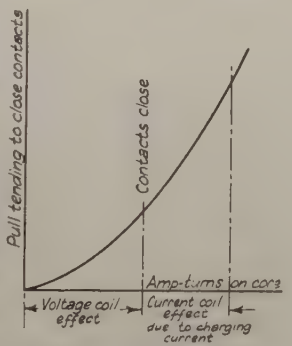
Pull tending to close contacts
Contacts close
Amp-turns on core
Voltage coil effect
Current coil effect due to charging current

Fig. 22.—Magnetic pull in reverse-current relay.

Action of Cut-out in Charging Circuit.—In Fig. 23 the connections of the charging circuit are shown, the coils being represented in a diagrammatic manner. The ammeter is a centre-zero instrument, and can therefore indicate either a charge or discharge current by the pointer deflecting to the right or left. The load—lamps, etc.—is seen to be placed between the ammeter and the cut-out. The starting motor, however, takes too large a current for the ammeter, and is therefore connected between

the battery and the ammeter. The charging circuit is controlled by the field switch, one terminal of the generator being connected directly to the cut-out, and the other terminal to the battery, or to earth, as the case may be.

When the field switch is closed and a charging current flows, which is the normal condition, the currents in both voltage and current coils flow in the same direction. The contacts are then held together by the combined pull of the two coils acting against the spring.

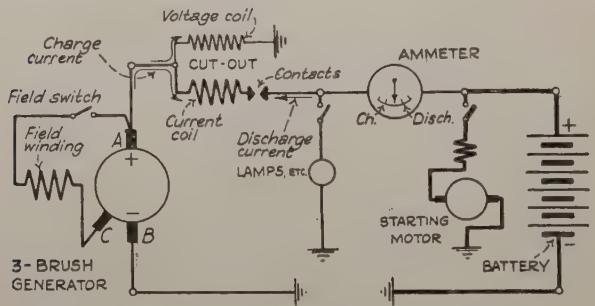

Fig. 23.—The charging circuit.

When, however, the current in the series coil reverses owing to a discharge current flowing from the battery, which takes place when the induced electromotive force of the generator falls below the battery voltage, the magnetic effect due to this coil also reverses in direction. Though the magnetic pull due to the voltage coil tends to keep the contacts closed, the current coil now assists the spring in bringing them apart.

The action of the cut-out is entirely automatic, and its function is to switch the generator in and

out of circuit according to the speed of the engine. Generally speaking, when the relay is once correctly set, it should not need further attention. It is important to keep the contacts clean and the connections tight. Also, it is well to get into the habit of noting the ammeter needle when the autocar is stopped, to make sure that the battery is not discharging into the generator. This may happen through the contacts sticking—usually a tap is enough to separate them.

In the case of cut-outs having a polarised core, the magnetism produced by the current and voltage coils acts upon a core which possesses a definite permanent magnetisation. Care must, therefore, be taken that the connections marked " Positive " and " Negative " on the cut-out are not reversed.

CHAPTER V

THE IGNITION SYSTEM

The ignition system considered here is that in which a high-voltage spark is used to ignite the fuel in the cylinders. The spark passes between the electrodes of a sparking plug within the mixture to be fired. There are two ways of producing the spark—by means of a magneto, which is a self-contained unit; or by means of a coil, which is operated from a battery.

The Petrol Engine

There are certain points about ignition connected with the working of the petrol engine that should be understood.

The Four-Stroke Cycle.—The internal combustion engine, as used on autocars, completes its cycle in two revolutions of the engine or four strokes of the piston. In the first (downward) or *suction* stroke, the explosive mixture is drawn into the cylinder. During the second (upward) stroke—the *compression* stroke—the mixture is compressed into the combustion chamber at the top of the cylinder. Towards the end of the second stroke, or at the beginning of the third stroke, the compressed gas is fired, and the succeeding or third (downward) stroke is called the *power* stroke. In the fourth (upward) or *exhaust*

stroke the burnt gases are expelled from the cylinder. The cycle is thus complete in two revolutions.

These actions are carried out automatically by the aid of valves or ports operated at the correct instants by cams mounted on a shaft which revolves at half the speed of the engine. Thus each cylinder must have an inlet valve and an exhaust valve, and

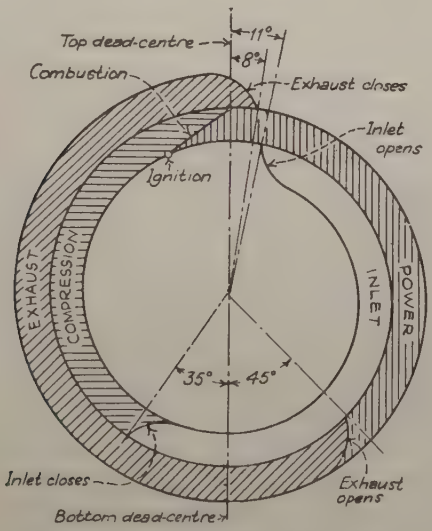

FIG. 24.—Typical four-stroke cycle.

both of these valves remain closed during the compression and power strokes. The settings of the valves in a typical case are shown in Fig. 24. An indicator diagram enables us to judge whether the adjustments are correct for obtaining good working conditions.

The Indicator Diagram.—In Fig. 25 the diagram

of cylinder pressures during a complete cycle is shown. The inlet valve opens when the pressure in the cylinder is at about atmospheric pressure, and the partial vacuum created by the moving piston draws a mixture of petrol and air into the cylinder. The inlet valve then closes, and the contents of the cylinder are compressed by the upward travel of the piston to a pressure of 70 to 80 lb. per square inch, when a spark is passed between the sparking-

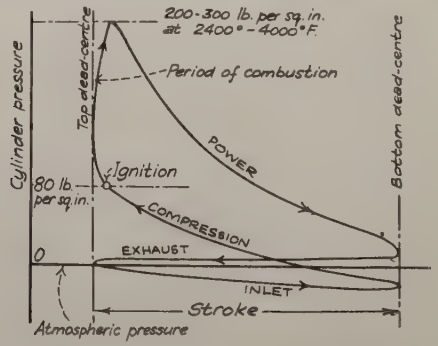

Fig. 25.—Indicator diagram of four-stroke cycle.

plug electrodes. The gases being thus fired, the pressure rises to 200 to 300 lb. per square inch—the explosion pressure being usually about four times the compression pressure. The piston should be at the top dead-centre, ready to begin its downward or power stroke, when this occurs. The temperature in the cylinder may reach 2,000° to 4,000° F. at this instant. This large force on the piston drives it downwards, and in so doing performs mechanical work in driving the engine. Towards the end of the power stroke the exhaust valve opens, and the

pressure in the cylinder falls to atmospheric pressure as the cycle is completed.

Firing Order of Cylinders.—It has been seen that in each cylinder of an engine working on the four-stroke cycle there is one power stroke in every two revolutions. Thus with a single-cylinder engine the torque is not uniform, and a large fly-wheel is required to avoid too great irregularities. Usually,

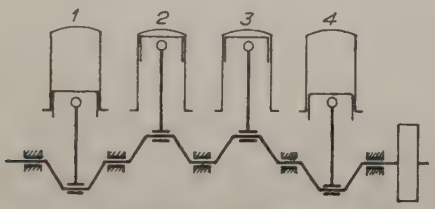

FIG. 26.—Crank arrangement in four-cylinder engine.

car engines are built with several cylinders, to provide as even a torque as possible, and so need comparatively small flywheels. The order of firing in the cylinders is also arranged to produce even running. Consider, for example, the common case of a four-cylinder engine (Fig. 26). The firing order can then be arranged in either of the following ways :—

Order of cylinder firing.		Stroke.			
First alternative.	Second alternative.				
1	1	*Power.*	Exhaust.	Suction.	Compression.
2	3	Compression.	*Power.*	Exhaust.	Suction.
4	4	Suction.	Compression.	*Power.*	Exhaust.
3	2	Exhaust.	Suction.	Compression.	*Power.*

Clearly the ignition system must be arranged to correspond with the firing order of the cylinders.

Effect of Mixture on Ignition.—The proportion of petrol vapour to air which will provide an explosive mixture may vary considerably. For petrol the correct mixture is about 15 parts of air by weight to 1 part of petrol; but a rich mixture may have a proportion as high as 11 to 1, and a weak mixture as low as 17 to 1. A mixture that is too rich emits a black smoke from the exhaust. The excess petrol in such a mixture, being incompletely burned, deposits carbon in the cylinder, and may produce back-fire in the silencer. With too weak a mixture a feeble and slow ignition results, and the period of combustion may continue beyond the exhaust stroke and ignite the incoming charge, thereby causing a blow-back in the carburetter.

The speed of combustion varies with the mixture. It is greatest in a mixture rather richer than the correct theoretical value for complete combustion, and in general decreases as the mixture becomes stronger or weaker. This effect, however, is rather offset by the turbulence of the gases in the combustion chamber.

Combustion.—The combustion of the gases requires an appreciable time, and should not be regarded as an instantaneous explosion. The gases in the cylinder are in a turbulent state; consequently the flame initiated by the passage of a spark across the plug electrodes is rapidly propagated throughout the mixture, causing a rapid rise in temperature and pressure. What appears to be needed, therefore, is not a long-drawn-out spark,

but a sharp, sudden breakdown of the gap between the electrodes by means of a rapid rise of voltage between them. Any previous leakage of current due to foul plugs or dirty contacts will be detrimental as tending to suppress the spark or upset the timing; while lingering of the discharge after the gap has been broken down will probably not be of further service, and will consume the plug electrodes unnecessarily.

The value of rapid propagation of the flame is evidenced by the increased power obtainable in a large cylinder with two-point ignition—that is, by firing the mixture in the cylinder from two plugs simultaneously. Such a device accelerates combustion, and in doing so reduces the time required for the pressure and temperature to reach their maximum values. These values are more likely to be reached, therefore, at the instant they are wanted, namely, at the top dead-centre, than when the process is a lingering one due to a slower rate of combustion.

Also, the spark-gap distributer may contribute to this end by preventing leakage before the spark passes across the electrodes. The energy, when released, is more concentrated and rapid, thereby ensuring more accurately-timed ignition.

For good ignition, therefore, it would appear to be desirable to have a sharp, sudden, snappy spark, with the energy emitted very quickly, rather than a slow, drawn-out discharge releasing, possibly, a larger total amount of energy. Not only must the sparking voltage rise very rapidly, but also the leakage conductance in the sparking plugs should be

low ; while the timing of the spark in each cylinder should be accurate, precise and identical. The correctly-proportioned mixture should possess a high degree of turbulence in the cylinder, while the fuel should be as thoroughly volatilised as possible before admission. Though a feeble spark may produce ignition, the best results will not be obtained unless the above conditions are satisfied.

Spark Advance and Retard.—In order to obtain the maximum power from the engine, the maximum pressure must be reached when the piston is at the top dead-centre. Owing to the time necessary for flame propagation in the cylinder to produce this result, ignition must occur before the end of the compression stroke. For this reason the ignition system is arranged so that the spark can be suitably advanced as the speed increases.

On the other hand, to produce maximum pressure at the right instant at low speeds the spark is needed later. For this purpose the spark has to be retarded. Failure to do this may cause knocking or pinking, due to the thump on the piston when the maximum pressure occurs before top dead-centre is reached. Also, when the engine is heavily loaded, as when climbing a hill, though the speed may be fairly high, knocking may also occur unless the spark is retarded. In this case the thump on the upward stroke of the piston is caused by the fuel admitted being in excess of that for which the spark is correctly timed.

Good results are usually obtained with the ignition advanced as far as possible without causing knocking.

The Induction Coil

Method of Obtaining a High Voltage.—In order to send a spark across the points of the sparking plug a voltage of 4,000 to 8,000 volts is necessary. To generate this voltage a special device is employed. It has already been mentioned that the electromotive force induced in a circuit is proportional to the rate of change of the magnetic field linking the circuit. It makes no difference whether the circuit moves and the field remains stationary, or the field itself changes while the circuit remains stationary. Provided there is relative movement between the magnetic field and the electric circuit, an electromotive force will be induced, and its value will be proportional to the rate of change of the linkages of the field with the circuit.

The number of linkages in a circuit is the number of lines of magnetic force multiplied by the number of turns through which they thread, so that for a given magnetic field the linkages are proportional to the turns. If the effect of magnetic leakage is ignored, by doubling the number of turns in a circuit the induced electromotive force is doubled for a given change of magnetic field. For this reason, where a high electromotive force is required, a coil with a large number of turns is employed.

Principle of the Induction Coil (Fig. 27).—A coil containing about 200 turns of thick wire is wound on a core made of iron wires or laminations and connected to a battery. In the circuit are two contacts, one fixed and the other movable. The movable contact, called a trembler, consists of iron

which can be influenced by the strong magnetic field produced in the iron core when current flows in the coil. When the movable contact is drawn towards the iron core, the circuit is broken and the field collapses. This permits the trembler to jump back again and close the circuit, and so the cycle repeats itself so long as the switch remains closed. The trembler thus rapidly makes and breaks the circuit ; with every make the current flows, and with every break it is interrupted. In this way the magnetic field grows and collapses alternately, and while it

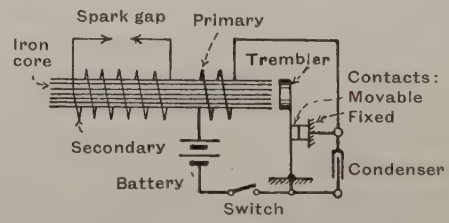

Fig. 27.—Elements of induction coil.

is being created and destroyed an electromotive force is induced which is proportional to the rate of change of the field linkages. Owing to the fact that the time taken to interrupt the current is much less than the time taken for it to build up, the voltage induced on break is much greater than that produced on make. The sluggishness in the building up of the current is due to the inductance of the circuit, inductance in an electric circuit being analogous to inertia in a machine. The winding in which this action takes place is called the " primary."

On the same core and linked with the same field is another coil, called the " secondary." This con-

sists of about 16,000 turns of fine wire. The electromotive force induced in every turn, whether primary or secondary, is the same, because every turn is embraced by the same magnetic field. It follows that the voltage induced in the secondary winding is much greater than that set up in the primary winding. The ratio between these two electromotive forces is obviously the ratio of the number of turns in the two coils. In this way an electromotive force of many thousand volts is induced in the secondary every time the current in the primary is broken. The terminals of the secondary coil are arranged to form a spark gap across which a discharge current flows in the form of a spark every time the primary circuit is broken. This is the spark that is used to fire the charge in the cylinder of the engine.

The Condenser.—Just as energy is released in the secondary circuit every time a spark jumps across the gap, corresponding with the collapse of the magnetic field, so energy is released in the primary circuit owing to the same cause. Hence at the trembler contacts there will be a succession of sparks. This discharge in the primary circuit has a twofold disadvantage : it causes pitting at the contacts and it reduces the energy released across the secondary spark gap. To reduce sparking in the primary circuit, a condenser is connected across the contacts as shown in Fig. 27. A condenser consists of two sets of sheets of tinfoil, insulated from one another by sheets of mica or waxed paper. When a voltage is applied to the terminals of a condenser, a momentary current flows, electric energy is stored, and the condenser becomes charged as shown in Fig. 28.

Charging current ceases as soon as the voltage ceases to change. The condenser can discharge the stored energy through any circuit provided for it, and this gives rise to a reverse or discharge current.

Referring now to Fig. 27, as soon as the contacts break the circuit the field collapses and a rapidly-varying electromotive force is induced in the primary circuit. Instead of forming a spark across the contacts, the current charges the condenser. Charging ceases as soon as the voltage ceases to change, and as the condenser circuit is closed the condenser discharges itself through the primary. This discharge current of the condenser in its turn produces a field in the core, and so sets up an electromotive force in the secondary, with the result that the energy released from the condenser reappears at the secondary spark gap, and so helps to bring about the desired effect. Thus, in addition to preventing burning of the contacts, the condenser helps to produce a better spark at the secondary gap.

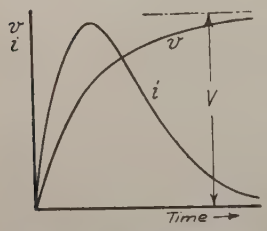

FIG. 28.—Voltage v and charging current i of a condenser.

Thus the condenser forms an integral part of both coil and magneto ignition systems.

In this connection an interesting experiment may be made with an induction coil by comparing the sparks at the secondary gap and at the primary contacts, with and without the condenser in circuit. When the condenser is cut out, vicious sparking occurs at the primary contacts, while at the

secondary gap the spark becomes both feeble and irregular. This occurs when the condenser of a coil or magneto is open-circuited.

With the exception of the contact-breaker, which replaces the trembler, and the distributer, which provides each cylinder with its spark at the correct instant, we have in the foregoing a description of battery-coil ignition.

As regards magneto ignition, the only difference

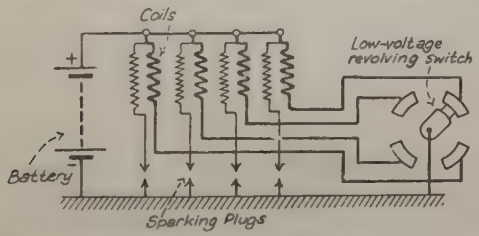

FIG. 29.—Arrangement with a coil for each cylinder and a revolving switch.

in principle is the replacing of the battery for providing the primary current by a generator, which is incorporated with the magneto.

THE DISTRIBUTER

It would, of course, be possible to have an induction coil for each cylinder, as shown in Fig. 29, arranged to supply a high-voltage spark at the correct instant by means of a suitable make-and-break device, such as a revolving switch in the low-voltage circuits. Such complication, however, is needless if a revolving switch, or distributer, is placed in the high-voltage circuits as shown in Fig. 30.

In practice the distributer is arranged in one of two ways: the contact type and the spark-gap type.

Contact-Type Distributer.—In this type a number of segments, equal to the number of cylinders and connected to the sparking plugs, are arranged at equal distances in a circle on the distributer head, which is made of moulded material. A carbon brush attached to the end of a revolving arm makes

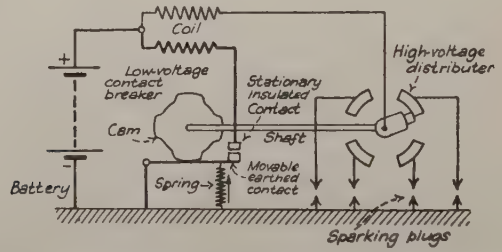

Fig. 30.—Arrangement with a single coil, distributer and contact-breaker.

contact with these segments as it passes them one after another. The centre of this arm is joined to the terminal of the secondary coil, so that the current is led to the several sparking plugs in correct order. For proper working the brush should take a fine polish and have free movement. With wiping contacts of this kind a certain amount of attention is needful. The track should be cleaned with an oily rag once in about every 1,000 miles to prevent leakage currents, sticking or cutting.

Gap-Type Distributer.—Here there is no brush at the end of the revolving arm, but the end is separated from the distributer segments by a small air

gap, across which the spark jumps. The electrodes are commonly made of nickel, and the gap is 0·01 to 0·015 inch. The actual gap length is not very important and, although it is in series with the sparking-plug gap, its presence makes but little difference to the voltage required. It is essential to ventilate the distributer head with this type of distributer, which can easily be done, in order to prevent the accumulation of ozone and nitric acid due to ionisation ; but periodical cleaning, as with the contact type, is unnecessary. By isolating the secondary winding in this way while the voltage is rising, leakage in sooty or oily plugs is avoided. The rise of voltage is therefore more rapid, for the gap may be regarded as a spark intensifier, and better results should ensue.

Speed of Distributer.—It has been seen that in the four-stroke cycle each cylinder needs a spark in every two revolutions of the engine. Consequently the speed of the distributer arm must be half the engine speed, or

$$\text{distributer speed} = \frac{\text{engine speed.}}{2}$$

The Contact-Breaker

Construction.—Instead of the trembler used in the induction coil, a more definite and reliable device, known as a contact-breaker, is employed with coils and magnetos. Of the two contacts, one is movable and makes connection with the primary winding and the condenser. The other is stationary with respect to the contact-breaker, and is connected to the other ends of the primary and the condenser.

The contacts are opened and closed by means of a cam, the lobes of which press against a fibre heel fixed to one end of a lever arm. At the other end of the lever arm is the movable contact, while the arm is arranged to rock about a spindle near its centre. A spring presses on this arm to keep the contacts closed except when they are opened by the cam.

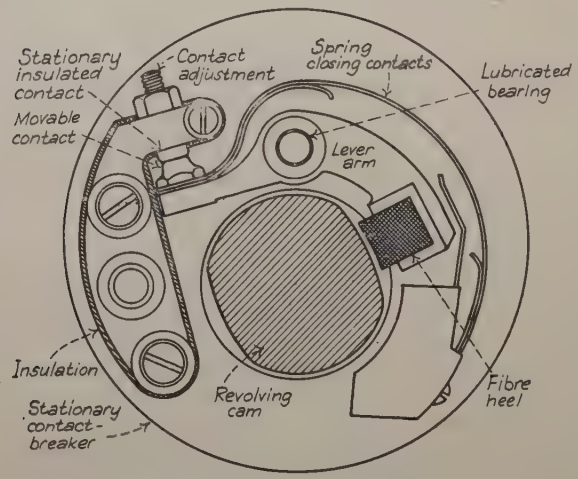

Fig. 31.—Stationary contact-breaker with revolving cam. (Actual size.)

As will be seen from Figs. 31 and 32, the cam can be either inside or outside the contact-breaker, according as the primary winding is stationary or revolving. Thus with a coil or a magneto with stationary winding the cam revolves inside the stationary contact-breaker (Fig. 31). With a rotating-armature magneto the contact-breaker revolves inside the cam (Fig. 32). The stationary contact is

insulated with both constructions, but the movable contact is earthed or insulated as required; in a magneto it is usually earthed, but with a coil it may be insulated. In the case of the magneto, the insulated contact is connected to the magneto earthing switch to enable the driver to put the magneto out of action.

From a mechanical point of view, the stationary contact-breaker is the more satisfactory arrange-

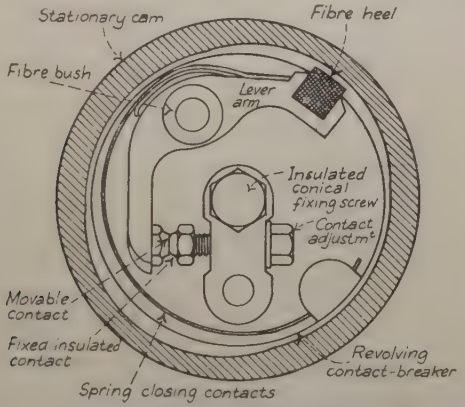

FIG. 32.—Revolving contact-breaker with stationary cam. (Actual size.)

ment. The mechanism can be made much more rigid, as space is not so limited, while considerations of centrifugal force do not arise. Consequently the stationary contact-breaker is less likely to need periodical adjustment than the revolving contact-breaker.

The lever arm is a vital part of the mechanism. It must act with precision, and there must be neither slackness nor sticking. With the revolving

type it is usual to mount the lever arm on a fibre or bakelised fabric bush, and, unless proper precautions have been taken, trouble may arise owing to the bush swelling, thereby preventing the arm from rocking freely. With the stationary type the whole construction is more substantial. The control spring can be made much stiffer, even to give a pressure of 2 lb. on the contacts when closed. The fibre bush can be dispensed with and a lubricated phosphor-bronze bush employed.

Speed of Contact-Breaker or Cam.—The speed of the contact-breaker or cam will depend on the number of sparks produced by it in one revolution, that is, on the number of lobes on the cam. With the coil the number of lobes can be chosen at will; with the magneto there will be two or four lobes, according as the machine is a two-spark or four-spark magneto, though some of these may be omitted when not required.

Since every cylinder needs a spark in every second revolution of the engine, it follows that:—

number of sparks needed per revolution of engine
$= \frac{1}{2} \times$ number of cylinders;

hence, number of sparks needed per minute
$= \frac{1}{2} \times$ number of cylinders $\times$ engine speed.

Thus, speed of contact-breaker or cam

$$= \frac{\text{number of sparks needed per minute}}{\text{number of sparks produced per revolution of contact-breaker}}$$

$$= \frac{\text{number of cylinders} \times \text{engine speed}}{2 \times \text{number of sparks produced per revolution of contact-breaker.}}$$

(*a*) *Speed with Coil Ignition.*—Here it is usual to have as many lobes on the cam and as many segments on the distributer as there are cylinders in the engine. Hence,

number of sparks produced per revolution of cam
= number of cylinders.

Thus, speed of cam
= $\frac{1}{2}$ × engine speed
= distributer speed.

Consequently with coil ignition the cam and distributer are mounted on the same shaft, which is made to revolve at half the engine speed.

(*b*) *Speed with Magneto Ignition.*—The contact-breaker or cam is mounted on the magneto shaft. In the following table the magneto speeds obtained from the above general formula are given for four-, six- and eight-cylinder engines using either two- or four-spark magneto :—

Number of engine cylinders.	Speed of Magneto.	
	With 2 sparks produced per revolution = 2-spark magneto.	With 4 sparks produced per revolution = 4-spark magneto.
4	engine speed.	$\frac{1}{2}$ × engine speed.
6	$1\frac{1}{2}$ × engine speed.	$\frac{3}{4}$ × engine speed.
8	2 × engine speed.	engine speed.

Adjustments of Contact-Breaker.—The correct adjustment of the contacts is of utmost importance in order to ensure correct action. When the contacts open, the primary current—some 3 to 5 amperes—is interrupted, and the stored energy, increased

by the buffer action of the condenser, is released at the sparking-plug electrodes. Injurious sparking at the contacts is prevented by the condenser taking the current rush, and so relieving the contacts of a slow, prolonged discharge which would not only pit the surfaces, but also reduce the discharge at the plug. The more perfectly the inductance or electrical inertia of the circuit is neutralised by the capacity of the condenser, the less will be the sparking at the contacts. The contacts should open at the instant the primary current reaches its maximum ; at any other instant the best effect will not be obtained. Similarly in closing, the best instant is that in which the induced electromotive force in the primary circuit is zero. If the contacts close too soon or too late, the current will not rise to its maximum value, and part of the effect will be lost. The correct adjustment of the contacts is, therefore, all-important. Just as the proper working of the engine depends on the correct setting of the tappets, so the proper working of the ignition system depends on the correct setting of the contacts.

In a magneto the correct opening of the contacts is 0·012 inch, and this should not vary more than one-thousandth of an inch in either direction. With coils the gap is made somewhat larger—namely, 0·015 to 0·02 inch—but the maker's figure should be strictly adhered to.

Further, to prevent burning or pitting, the contacts must be kept clean ; oil or dirt will rapidly cause trouble. The primary resistance is only about 0·5 ohm. A film of oxidised oil spoils the contact by introducing resistance, thereby reducing the

primary current and causing unsatisfactory sparking at low speeds.

Until recently, contact points were made of an alloy of platinum and iridium, the proportion of the latter being 20 to 25 per cent. of the whole. These rare metals are very costly, and tungsten is now largely employed for this purpose. With correctly-designed parts good results have been obtained with tungsten contacts.

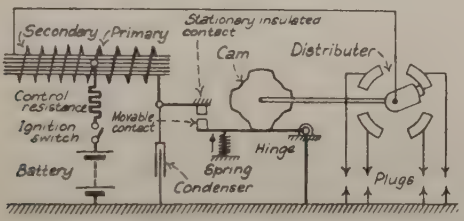

FIG. 33.—Elements of coil ignition.

As regards lubrication, etc., the maker's instructions should be followed.

BATTERY-COIL IGNITION

Arrangement.—The arrangement of battery-coil ignition is very simple, as seen from the diagram of connections in Fig. 33. The coil, consisting of a primary and a secondary winding on an insulated iron core, and the condenser, are both stationary. The core is a bundle of laminations or soft iron wires. The primary consists of two layers of copper wire with a resistance of less than 0·5 ohm. The secondary has about eighty times as many turns as the primary, and a resistance of 2,000 to 4,000 ohms. The coil is impregnated to render it moisture-proof. The

distributer and the cam are mounted on the same shaft and driven at half engine speed, the contact-breaker being stationary. One end of the battery is connected to the junction of the primary and secondary windings, while the other end is connected to the movable contact of the contact-breaker, either by a wire or through the frame, as shown in the figure.

A switch is placed between the battery and the coil.

The current consumption is 0·5 to 2 amperes, so that the battery is usually kept continually on charge where coil ignition is used. As the coil is operated with direct current, all the distributer leads have the same polarity.

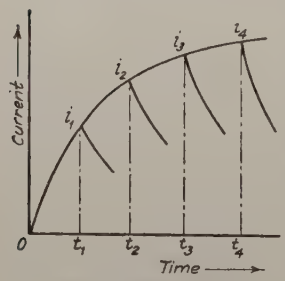

Fig. 34.—Effect of speed on coil ignition.

Effect of Speed.—In an inductive circuit, such as we have in the coil, the current does not rise instantaneously to its final steady value, but a certain interval of time is required for this purpose after the contacts are closed. When the speed is low the current attains a higher value than when the speed is high, because then the contacts remain longer closed. This effect is illustrated in Fig. 34, which represents the rate of growth of the current in the primary circuit. At starting or at very low speeds the current has time to rise to i_4. As the speed rises, the interval during which the contacts

remain closed becomes shorter and shorter, so that at t_3, t_2 and t_1 the current only rises to i_3, i_2 and i_1 respectively. From this it follows that the current interrupted at low speeds is larger than at high speeds, and the strongest sparks are, therefore, produced at starting and when the engine is running slowly.

This is what is wanted, and enables many engines to start more easily with coil than with magneto ignition. The comparison, however, must not be pushed too far, for many modern magnetos can compete with the coil at low speeds, while at high speeds the magneto, the voltage of which rises as the speed rises, produces better ignition than the coil, the voltage of which falls as the speed rises. Nevertheless, the strong spark at very low speeds must be accounted one of the chief merits of coil ignition.

It must be remembered, however, that the coil is operated from the battery, and if the battery voltage is low, as during the interval when the starting motor is in circuit, or when the battery is run down, this superiority will not be so pronounced ; indeed, under adverse conditions, starting with coil ignition may be more difficult in some cases than with magneto ignition.

The Control Resistance.—In Fig. 33 it will be noticed a resistance is connected in the circuit between the battery and the coil. This resistance is made of wire, the resistance of which increases rapidly with the temperature. The function of this control or ballast resistance is a twofold one.

(*a*) *Protective Action.*—If the ignition switch is

left closed when the engine is not running, and the breaker contacts are closed, the battery will continue to discharge through the primary circuit. Unless some current-limiting device is present, the coil may heat up sufficiently to burn out before the battery is discharged. By using an external control resistance which heats up and reduces the current, the coil is prevented from overheating, and the battery from rapid discharge. Also, if the battery becomes disconnected from the generator, the control resistance may act as a fuse to the current due to excessive generator voltage and so protect the coil from damage.

(*b*) *Regulator Action.*—With additional resistance in the circuit the current reaches its final value more rapidly, though that final value is reduced. Relatively, therefore, the conditions are better at high speeds with a resistance in circuit than without such a resistance. The resistance thus keeps the secondary voltage more constant over the speed range, though it reduces its maximum value.

Obviously, the effect of voltage drop in the control resistance must be taken into account when designing the coil, but voltage drop has to be allowed for in any case to compensate for the adverse conditions which exist when starting electrically with the battery partly discharged. An actual test showed that with a half-charged battery and electric starting, the maximum spark energy was half that with a fully-charged battery and hand starting.

Dependence on Battery and Dynamo.—Though the coil is cheaper to manufacture than the magneto, owing to the much smaller amount of precision work

and the simpler construction, it must be remembered that, in addition to the coil, the battery and charging generator are indispensable parts of this system of ignition. This multiplicity of essential parts is doubtless a drawback of coil ignition, for both battery and dynamo are liable to breakdown. Though a coil is a simpler addition to the electric equipment than a magneto, the fact remains that coil ignition converts the lighting battery and generator into integral parts of the ignition system.

Magneto Ignition

Action of the Magneto.—The magneto is a self-contained unit. The machine being an alternating-current generator, the primary current in the magneto is produced by the electromotive force induced in the primary coil. The field is provided by a permanent magnet. Thus no battery is needed either for energising the primary or for producing the magnetic field. The secondary, condenser, distributer and contact-breaker are incorporated in the magneto. Only high-voltage magnetos, that is, magnetos in which a secondary winding is used, are discussed here.

When the magneto is rotated, an electromotive force is induced in its windings by the change in the number of field linkages. A glance at Fig. 35 will show that the number of linkages of the magnetic field with the armature windings is a maximum in the positions marked *a*, *c* and *e*. In positions *b* and *d* there are no linkages between the field and the windings. In intermediate positions the linkages will vary, as shown by the curve marked "field

linkages." Now, the induced electromotive force depends on the rate of change of the field linkages. Hence at *a*, *c* and *e*, where the number of linkages does not change at all, the induced electromotive force is zero. At *b* and *d* the linkages are zero, but the rate of change in the number of linkages is greatest, and consequently the induced electromotive force reaches its maximum value in these

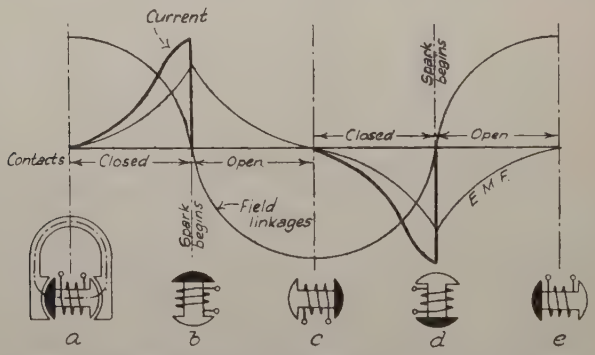

FIG. 35.—Field linkages, induced electromotive force and primary current in two-spark magneto during one revolution.

positions. Since the direction of the field change at *b* is opposite to that at *d*, the induced electromotive force will be positive in one position and negative in the other. Thus the induced electromotive force in a magneto is alternating. The curve marked " E.M.F." in Fig. 35 will serve equally well to denote the electromotive force induced in the primary or in the secondary, their relative values depending on the ratio of turns in the two windings. If the maximum value of the electromotive force induced

in the primary is 50 volts and there are 50 times as many turns on the secondary as on the primary, then the maximum value of the secondary electro-motive force will be $50 \times 50 = 2{,}500$ volts.

The contacts in the primary circuit are arranged to close when the induced electromotive force is zero, that is, at *a* and *c*, and to remain closed until the electromotive force reaches a maximum, that is, at *b* and *d*. Whilst the contacts are closed a current flows in the primary winding (see Fig. 35), attaining a maximum value of 3 to 5 amperes. Owing to this primary current, an armature field is produced (in addition to the main field of the magneto) and is linked with both primary and secondary windings. At the instant the current reaches its maximum value the contacts open, the current is interrupted, and its field collapses. This sudden collapse of the armature field through the primary current being interrupted, induces a large electromotive force in the windings. In the secondary winding this sudden and large addition to the electromotive force induced in this winding by rotation suffices to send a spark across the plug electrodes. This discharge is further reinforced by the action of the primary circuit, in which the energy released by the interruption of the primary current charges the condenser, which in turn discharges and transfers its energy to the secondary circuit. The reversal of the main flux at the instant the contacts open also assists in reducing the armature field rapidly to zero. At a magneto speed of 1,000 revolutions per minute the voltage across the electrodes may be 4,000 to

5,000 volts, producing a discharge current of about 0·03 ampere.

The small secondary reactions which make the optimum " break " position somewhat later than that shown in Fig. 35 need not concern us here. It is not possible to obtain one optimum " break " position for all speeds and positions of the timing lever. Consequently it is customary to time the magneto to break the primary circuit when the current is at its maximum value at low speeds in the fully-advanced position. At high speeds, and with the lever in the retard position, the best result is not obtained, but extended poles are now almost universally employed to improve matters in this respect. Some automatic timing devices also maintain the advance spark position with retarded ignition.

A great improvement in magnetos has been effected by the use of laminated instead of solid pole pieces, the improvement consisting of a greatly increased rapidity in flux changes and a considerable reduction in the loss due to eddy currents in the iron.

The Safety Spark Gap.—If by chance a high-voltage wire should become disconnected, the voltage in that circuit might be high enough to endanger the winding unless a suitable discharge path were available. It is usual, therefore, to provide a safety spark gap inside the magneto, adjusted to operate in case the secondary voltage exceeds a certain predetermined value. The safety spark-gap consists of an earthed electrode and an electrode connected to the high-voltage terminal of the secondary winding. This gap may be stationary,

but it is frequently made to revolve by attaching the electrodes to the gear wheel on which the distributer arm is fixed. By causing the gap to revolve in this way, any injurious effects arising from ionisation are prevented.

Method of Driving.—The magneto is driven by the engine. A flexible coupling is desirable to reduce stress on the magneto spindle. Some form of vernier coupling is often used to facilitate fine adjustment in the timing. Thus in one coupling there is an intermediate rubber member which has 20 teeth on one side and 19 on the other. With this it is possible to obtain a vernier adjustment of $1/19 - 1/20 = 1/380$ of a turn —that is, less than 1 degree— by shifting one side forward and one side backward each one tooth.

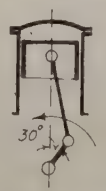

Fig. 36.—Position of piston with full advance of timing lever.

Timing with Engine. — Generally the best firing position with the timing lever fully advanced is given when the crankshaft is about 30 degrees ahead of the dead-centre position, the piston being on the compression stroke (see Fig. 36).

In a four-cylinder engine, where a two-spark magneto runs at engine speed, if the total angular movement of the timing lever is 25 to 30 degrees, the timing can be effected thus: Fully retard the timing lever and, with the armature in the position corresponding to the contacts just opening, adjust the coupling so that the piston is just on the dead centre. Connect the sparking plug of cylinder to

the distributer segment in contact with the brush (or electrode), and the other plugs to the other segments in their proper sequence.

Accurate and precise timing in all cylinders is important for good working of the engine. For this purpose, the contact-breaker, the distributer, the sparking plugs, the cams, camshaft and tappets must all be correctly fitted and adjusted.

Magnet Steel.—When a piece of iron is magnetised by placing it inside a coil of wire (or solenoid), it is possible to measure the magnetic field density produced by a given magnetising force. The field density denotes the number of magnetic lines produced in each square centimetre of the cross-section of the iron. This is denoted by B. The magnetising force is equal to $0{\cdot}8 \times$ magnetising current in amperes $\times$ number of turns per centimetre length of the magnetising coil. This is denoted by H. By gradually increasing the current a curve with B as a function of H is obtained ; such a curve is called the *magnetisation* curve. Each specimen of iron has its own magnetisation curve.

With both soft iron and steel, if the magnetising force is gradually reduced from a maximum value to zero, the magnetism does not follow the same law of variation as the exciting current. When the latter is zero it is seen from the curves in Fig. 37 that the magnetism remaining in these specimens is about 10,000 lines per square centimetre. This is called remanent or residual magnetism. Soft iron differs from steel in that it is very easy to demagnetise it completely when the exciting current is switched off. This may be done by a slight

mechanical force, or by the application of a small reverse value of the magnetising current. With steel, however, the material resists demagnetisation, even when roughly handled, while a much greater demagnetising value of H is required to reduce its magnetism to zero. A large proportion of the residual or remanent magnetism in steel is retained after the magnetising force has been removed. This is the permanent magnetism of the steel used in the

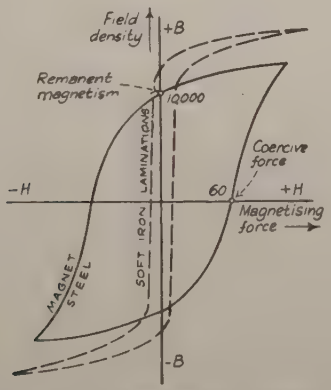

FIG. 37.—Cycles of magnetisation of soft iron and of magnet steel.

construction of magnetos. The name given to the demagnetising value of H required to reduce the magnetism to zero is "coercive force." In magneto steel, the remanent magnetism (B) may be about 10,000 and the coercive force (H) 60.

Since permanent magnetism is the essential feature of magneto steel, it follows that remanence and coercive force are here of prime importance. Experience has shown that $(BH)_{max.}$ denoting the

maximum value of the product of field density and demagnetising force during demagnetisation, affords a valuable criterion of the suitability of steels for permanent magnets. Alloy steels are used almost exclusively for magneto magnets, because it is found that steel alloyed with the practically non-magnetic metals tungsten, chromium and cobalt, show superior magnetic properties. The steel mostly used for magnetos is a 5 to 6 per cent. tungsten steel, while a 2 per cent. chromium steel

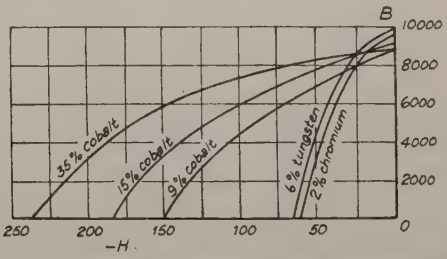

FIG. 38.—Typical B-H curves for various magnet steels.

is widely used in America. In recent years Japanese research has developed an alloy known as 35 per cent. cobalt steel, having a coercive force as high as 250, with a $(BH)_{max.}$ about three times that of tungsten steel. Thus a 35 per cent. cobalt steel magnet would have about one-third the volume and weight of a tungsten steel magnet for a given duty. The great drawback of cobalt steel is its high price. Nevertheless this steel has done much to enable such good results to be obtained with the polar inductor magneto. In Fig. 38 a series of curves of modern magneto magnet steels are reproduced from a paper

by Messrs. A. P. Young and L. Griffiths, read before the Institution of Automobile Engineers.

As an indication of the improvement in magnet steels, it may be mentioned that a modern magneto can be expected to retain its magnetism indefinitely, provided nothing occurs to destroy it.

If for any reason the rotor has to be removed, care should be taken to bridge the magneto with soft iron keepers before dismantling the magneto, and not to remove the keepers until the rotor has been replaced. Occasionally magnetos have become demagnetised by a current from the battery flowing through the primary winding owing to a fault in the wiring or switchboard.

With the appliances now used in factories and large garages, the magnets of a magneto can generally be remagnetised rapidly and cheaply without removing any part of the machine.

Types of Magnetos.—The magnetos used at the present day may be divided into three classes :—

(1) **Revolving-Armature Type,** in which the armature windings, condenser, and contact-breaker revolve and the magnet is stationary.

(2) **Revolving-Magnet Type**, in which the magnet revolves and the armature windings, condenser, and contact-breaker are stationary.

(3) **Polar-Inductor Type,** in which soft-iron inductors revolve and magnets, armature windings, condenser and contact-breaker are all stationary.

Revolving-Armature Magneto.—This is the commonest and oldest type of magneto. (See Fig. 39 at end of book.) Its magnetic circuit is shown in Fig. 40, and its electric circuit in Fig. 41. The field

system consists of one or more steel magnets shaped like an inverted U, and a shuttle or H type laminated iron armature. The primary and secondary windings, together with the condenser, are housed inside the armature. The common terminal of the two windings is connected to the insulated terminal of the condenser, to the insulated conical fixing screw and to the fixed insulated contact. The free ends of the primary winding and of the condenser are connected to the metal body of the armature, and a special earthing brush is provided to ensure a good electrical contact between the armature and the frame, engine, etc. If the earthing brush is faulty, current may pass through the ball races in which the armature revolves and cause pitting of the balls. An insulated cable is also taken from a brush rubbing on the conical screw to the magneto switch, by means of which the other end of the primary winding can be earthed, thereby putting the magneto out of action.

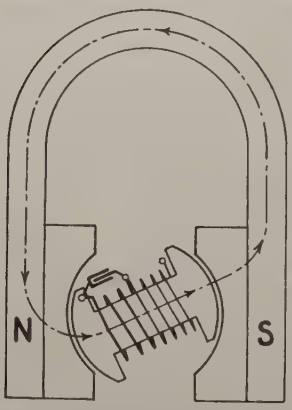

FIG. 40.—Magnetic circuit of revolving-armature magneto.

The free end of the secondary winding is taken to an insulated slip-ring, which revolves with the armature. The high-voltage current is collected here by means of a slip-ring brush and is conveyed to the revolving distributer brush or electrode by a

further brush, as shown in Fig. 41. It is essential that all parts are kept clean, particularly where carbon dust is likely to accumulate.

In magnetos of this type there may be as many as 50,000 lines in the magnetic field. To enable this field to pass readily from the magnet to the armature, not only is the air gap made small, but the poles are fitted with laminated pole shoes. Laminated pole shoes permit the field to change much more rapidly than cast-iron shoes, because of the reduced eddy current loss in the former, while

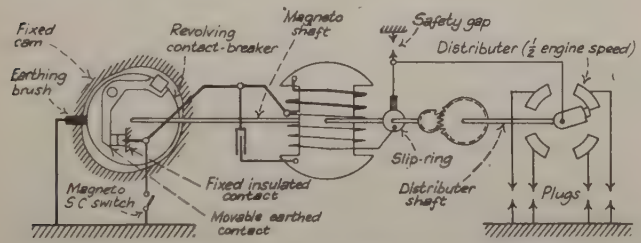

FIG. 41.—Elements of revolving-armature magneto.

extended pole tips improve the spark at low speeds with the time lever in the retarded position.

From the nature of their design, revolving-armature magnetos are essentially two-spark magnetos, but by omitting one cam a single spark per revolution can be obtained.

Revolving-armature magnetos are well suited for engines having up to four cylinders and for slow-speed six-cylinder engines.

Revolving-Magnet Magneto.—A section is shown in Fig. 42 at end of book, and the magnetic circuit of this type in Fig. 43. The revolving part consists of

a circular magnet or its equivalent, and the field completes its path through a circuit of laminated iron. The stationary windings and condenser are mounted on the detachable part of the magnetic circuit, called the core. The contact-breaker, like the windings, is stationary, the contacts being operated by a revolving two-lobe cam. It is possible to build the revolving magnet with four or even six poles, but space considerations may render this difficult. The case illustrated is the common one of a two-spark magneto.

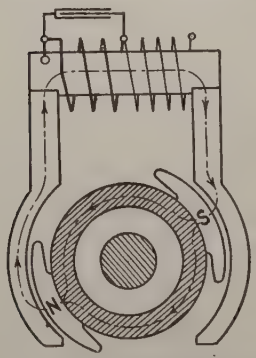

FIG. 43.—Magnetic circuit of revolving-magnet magneto.

It is interesting to compare the construction of this magneto with that of the revolving-armature type. In the latter the armature revolves together with its contact breaker; whereas with a revolving magnet the windings and contact-breaker are stationary. The latter form of construction has many advantages from a mechanical standpoint, but the stationary magnet makes it easier to provide a strong magnetic field. The revolving magnet is well suited for high-speed engines, and cobalt steel may lead to its wider use. A knowledge of the action of this type helps us to understand the polar-inductor magneto.

Polar-Inductor Magneto (Fig. 44 at end of book).—In the polar-inductor magneto the magnets are stationary, while the field reversals are produced by revolving soft iron polar projections called inductors.

This is illustrated in Figs. 45 and 46. The magnetic path is rather complicated, and the field has to cross four air gaps. It is a simple matter, however, to obtain a four-spark magneto by means of the four inductors shown in the illustrations. The magnet system consists of two straight cobalt steel magnets, the ends of which make contact with two laminated iron rings. Thus lines of force from a N-pole leave

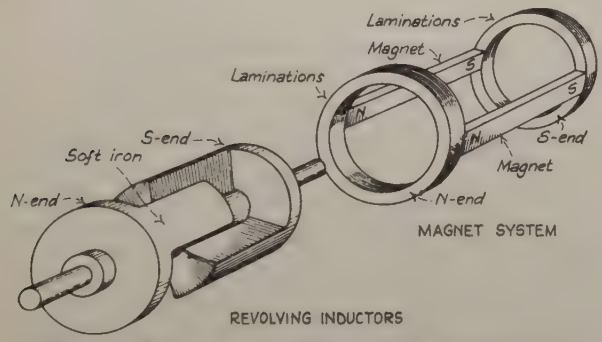

Fig. 45.—Magnets and inductors of polar-inductor magneto.

at one ring and enter a S-pole at the other. These lines induce N- and S-poles in passing through the revolving inductors—shown removed from the magnet system in Fig. 45—and complete their magnetic circuit through the laminations shown in Fig. 46. The total number of magnetic lines through the armature core in this type is about 25,000, and there are four field reversals in every revolution, thus giving a four-spark magneto. The electric circuits are shown in Fig. 47. The windings, condenser and contact-breaker are seen to be stationary,

as in the revolving-magnet type. The only brush is that which presses on the centre of the distributer wheel and conveys the high-voltage current from the secondary winding to the distributing electrode.

The four-spark polar inductor magneto is eminently suitable for high-speed engines and for engines with a large number of cylinders, since its speed is only half that of a two-spark magneto. At the same time, by using a two-lobe cam, it can be run at the same speed as the ordinary magneto, being now made to work as a two-spark machine. This higher speed enables the inductor type to give higher voltages and to supply all the plugs with sparks of the same polarity (see "Sparking Plugs").

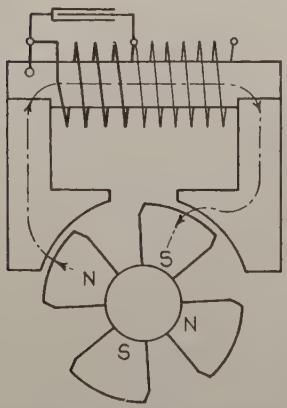

FIG. 46.—Part of magnetic circuit of polar-inductor magneto.

The polar inductor magneto is found to give a good spark at low speeds, owing to the rapid rise of the secondary voltage. This may lead to an improvement in both starting and running performance, especially when all plugs are supplied with sparks of the same polarity, thereby making the firing conditions alike in all cylinders.

Both mechanically and electrically, the polar-inductor type of magneto has distinct advantages over the revolving-armature type. It costs more

and it is heavier, but its reliability is greater owing to its higher factor of safety.

Automatic Ignition Timing Devices.—Correct timing of the spark depends on both the throttle opening and the engine speed, and devices have been constructed to deal with both these variables automatically. If the speed alone is to be considered, a simple centrifugally-operated mechanism can easily be interposed between the magneto and

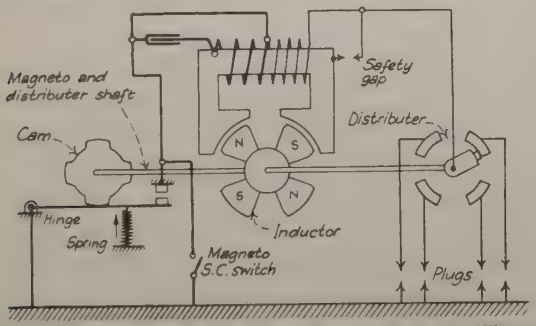

FIG. 47.—Elements of polar-inductor magneto. (Shown for four-cylinder engine with four-spark magneto running at half engine speed.)

the engine which will automatically advance the timing of the spark at a predetermined rate. With such devices the magneto itself is always fully advanced to give its best spark. Consequently starting is facilitated and low-speed running is improved, the necessary retard being obtained automatically.

Automatic timing control can be obtained with or without manual control. For simplified driving, automatic timing without manual control is satisfactory; but for obtaining the best engine efficiency

some manual control is necessary to compensate for throttle openings in excess of the normal, as when hill climbing. Where manual control is provided it is important to ensure ample range in the full advance position. For this purpose it is well to make the full advance position some 5 to 10 degrees greater than with manual control. The speed being corrected for automatically, the manual control only needs to be used for retarding the spark when the throttle opening is so large as to cause knocking. This combination retains the advantage of working with the magneto spark always in the best position, viz., full advance, except when manual retard is resorted to.

It is likely that these simple devices will become more widely used, since they lead to more economical running, less gear changing, improved acceleration and simplified driving. Moreover, since at starting the necessary retard is obtained on the automatic control, with the magneto fully advanced, easier starting results.

Sparking Plugs

Construction.—The sparking plug consists of a steel shell screwing into the cylinder head, thus forming the electrical connection to the frame, and an insulating bush of porcelain or mica. The electrodes or sparking points are fixed respectively to the earthed steel shell and to the insulating bush. There are many ways of doing this; hence the numerous varieties of plugs on the market.

Conditions of Operation.—The conditions under which sparking plugs have to operate are exacting.

In certain circumstances plugs must withstand voltages up to 7,000 volts at pressures as high as 500 lb. per square inch at temperatures up to 4,000° F., and furnish forty discharges per second.

Correct Position of Sparking Plugs in Cylinder.—In general, the inner edge of plug should be flush with inner surface of combustion chamber, so that the electrodes just extend into cylinder (see Fig. 48), though practice would seem to show there is no hard-and-fast rule in this matter.

If the shell extends beyond the inner edge of the cylinder, the plug may overheat and produce pre-

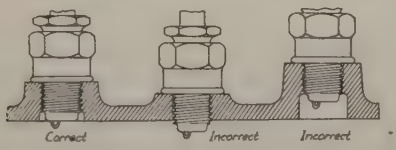

FIG. 48.—Correct and incorrect positions of sparking plug.

ignition. On the other hand, if the shell is kept inside the hole, a pocket for burned gases is formed and misfiring may result, as well as fouling from oil or carbon accumulation. Fouling provides a leakage path for the secondary discharge current. If the resistance of the leakage path be over 50,000 ohms, this shunting effect may not be serious; but bad fouling causes feeble and ill-timed sparking, and in bad cases, when the electrodes become short-circuited, misfiring. It is well for the plug to be so placed that it will be cooled by the gases during the intake stroke. A good position for the plug, therefore, is just opposite to the inlet valve.

Porcelain Plugs.—These are made much in the

same way as china is made—from kaolin, with fluorspar as binder, and fired to give a glazed surface. Glazing renders porcelain non-porous. Consequently, if the glaze is destroyed by excessive temperature or scraping, carbon will be absorbed and ignition may be vitiated or prevented.

Since the resistance of porcelain decreases as the temperature increases, cooling is important where porcelain plugs are used ; otherwise leakage may be troublesome.

Porcelain plugs may easily crack if clamped too tightly. The gland nut should secure a proper gas-tight fit and yet permit proper expansion.

Mica Plugs.—Mica does not conduct electricity at high temperatures as readily as porcelain, and is therefore a good insulator for high-temperature engines, such as air-cooled types.

Mica cracks readily when subjected to sharp bends, and it is common practice, therefore, to make the bush with mica washers pressed tightly between two binding heads. Care must be taken to prevent oil and petrol penetrating between the mica layers.

Electrode Construction.—Electrodes must be made of some metal which will withstand oxidation and burning. They should be proportioned to facilitate cooling, so as to prevent rapid burning away and consequent widening of gap. A common electrode is a 97 per cent. nickel alloy.

Shape of Electrodes.—A higher voltage is needed for sparking between rounded surfaces than between sharp points ; also from a flat surface to a sharp point than conversely.

This means that a spark is obtained at a lower

voltage when the earthed electrode (the pointed one) is positive than when it is negative. The difference may be as much as 500 to 1,000 volts.

With *coil* ignition, where the polarity of all the plugs is the same, it is a simple matter to make the earthed electrode positive.

With *magneto* ignition where the distributer terminals are alternately positive and negative, the plugs in which the earthed or pointed electrode is positive spark the more readily. In consequence these cylinders have better ignition sparks at starting and low speeds under heavy compression, the others being more apt to misfire under these conditions. Where engines always stop in the same position it is sometimes possible to obtain easier starting by changing the plug polarity. This can be readily done by moving all the distributer cables a segment forwards or a segment backwards. A four-spark magneto fitted with a two-spark cam—an arrangement possible with the polar-inductor magneto—gives sparks all of the same polarity.

Multiple-pointed Plugs.—When plugs have two or more points, the spark takes the one of least resistance. If all points are set alike, adjustment is needed less frequently because the proper distance is longer maintained.

Spark Gap Adjustment.—This depends on the engine compression and system of ignition. For magneto ignition the normal gap is 0·02 to 0·025 inch. With coil ignition the normal gap is 0·025 to 0·03 inch.

Two-Point Ignition.—With two plugs per cylinder, flame propagation is hastened and the spark advance reduced proportionately, leading to increase in

power and consequent fuel economy, though in high-speed engines with small cylinders the turbulence may be great enough to mask this effect.

Importance of Clean Plugs.—Apart from failures from petrol or oil in mica plugs, or from high internal conductivity of porcelain plugs caused by heat or deposition of carbon, a frequent source of trouble is the partial or complete short-circuiting of the plug by oil or soot between the electrodes, or an excessive deposit of carbon on the surface of the plug itself caused by popping back, etc. Plugs thus fouled are leaky, and the degree of the misfiring which results will depend on the resistance of the shunt leakage path thus produced. In some cases the trouble will clear itself; in others the plug may have to be removed and cleaned. In general, leakage is less likely to occur with spark-gap than with wipe-contact distributers.

Special Ignition Equipment for Starting

In order to start an automobile engine it is necessary to fill one or more of the cylinders with an explosive mixture and to fire this mixture by means of a suitable spark. It has been seen that a properly-designed starting motor operated from a battery of adequate capacity can be made to turn the engine at a speed sufficient to draw in the requisite mixture and produce a satisfactory spark from the magneto. With coil ignition the problem is usually simpler, because a coil can be made to produce a spark at a lower speed than a magneto. In either case the battery is necessary for the starting motor. Where expense is a secondary consideration, some

makers use both coil and magneto ignition, the former being used for starting and the latter for running, or as a reserve. A decided advantage of this dual arrangement is the provision of a reserve source of ignition, for if the coil fails the magneto is available, and *vice versâ*. Where a magneto with stationary windings is used, the connections from the switchboard to the common distributer, etc., for dual ignition become fairly simple.

In all cases up to the present considered there have been battery and starting motor. Some vehicles, however, are not fitted with batteries, while others may have batteries and motors which are not intended to rotate the engine at a speed sufficient to produce sparks from the magneto. The starting problem then resolves itself into the finding of other means of filling the cylinders with an explosive mixture and the production of a suitable spark. Various means are adopted for filling the cylinder or cylinders : a charge may be left in the cylinders by opening the throttle after ignition has been cut off, when shutting down ; the cylinders may be primed ; the engine may be cranked by hand or rotated by a motor.

Many devices, too, have been developed for producing the spark needed to fire the mixture. Some of these devices are for use with coil ignition, others with magneto ignition ; a great many of them are already things of the past.

Of the various devices used for starting, some rely on the battery for assisting the magneto current or for providing current for the spark, and consequently entail a certain amount of undesirable complication.

Others, of a purely mechanical nature, are simpler in character and involve the principle of a hand-operated magneto co-operating with the main magneto. In practice the former can be embodied in the latter if suitable auxiliary apparatus is provided; one well-known device for this purpose is the *impulse* starter. In this device there are two members linked together by a strong spring. One member is fixed to the magneto shaft, and the other to the driving shaft. By means of a pawl or trigger the magneto armature is prevented from revolving, and in consequence the spring is wound up as the engine is cranked. After a certain angle has been traversed the pawl releases the spring, which imparts to the armature a speed equivalent to about 500 r.p.m. for half a revolution. The spark produced by this rapid movement fires the mixture, thereby starting the engine, while at a low speed the pawl is thrown out of action by centrifugal force and the two members rotate as a single unit. The impulse starter would appear to be suitable for commercial vehicles and tractors.

A detailed discussion on special aids to starting would carry us beyond the elementary principles of electrical equipment, and for particulars of these devices the interested reader should consult the handbooks of the several makers.

Ignition Faults

R.A.C. records show ignition faults to be 20 to 25 per cent. of the total faults causing stoppages on the road. Here it is intended to discuss engine trouble arising from ignition faults only.

Ignition faults may cause misfiring or they may prevent the engine running at all. Misfiring in one or more cylinders may be due to faults in a section of the ignition system. Stoppage of the engine may be caused by the earthing of the switch cable, sticking of the rocker arm with contacts open, loose lock nuts or central screw of contact-breaker, break-down of magneto or coil to earth, disconnection or discharge of battery with coil ignition, dampness, oil, dirt, etc.

Pre-ignition may result from glowing particles of carbon, especially on low speed, high gear, and heavy load with dirty cylinders. *Backfiring* in the silencer may be due to an over-rich mixture, while too weak a mixture may cause *popping-back* in the carburetter (see p. 60).

Location of Ignition Faults.—Faults should be located in a methodical manner; much time may be wasted by haphazard methods. In case of *misfiring* in one or more cylinders, run the engine and locate the faulty cylinder.* This can be done by short-circuiting successive plugs to find which plug makes no difference in the running by means of a

* *Sparking-plug Tester.*—A simple, handy device consisting of a tube of neon gas in an ebonite case fitted with a metal cap at one end is now available for testing sparking plugs. The tube is held by the insulating case, while the metal cap is brought into contact with the sparking-plug terminal, the engine being run slowly. According to the flash observed in the tube, the condition of the plug can be judged and the appropriate remedy applied.

Observed Flash	*State of Plug or High-voltage Cable*
Bright and regular.	Good.
Feeble.	Plug dirty or electrode gap too small.
Irregular.	Plug or cable faulty.
No flash.	Plug short-circuited or break in high-voltage circuit.

short length of insulated cable or a screwdriver with a wooden handle. In any case, be careful to press one end of the cable or screwdriver firmly against the engine before touching the plug terminal with the other end, and to keep the hand insulated; otherwise a bad shock may result. Remove the high-voltage wire from the terminal of the suspected plug and hold it $\frac{1}{4}$ inch or less from cylinder; a spark will indicate that the plug is at fault. Overhaul plug for a short-circuit due to soot or oil on electrodes, carbon deposit on plug, or too large gap; then test the plug on cylinder cover by cranking the engine. If no sparking occurs at electrodes, try another (good) plug. If this is satisfactory, cracked porcelain or leaky mica in the original plug is probably the cause of trouble.

If no spark passes from the high-voltage wire to the engine frame, some fault arising from defective contact in the high-voltage wire, or in the magneto or coil, is indicated. Test the high-voltage cable by trying a new cable. If the new cable does not remove the trouble, look for cracked or leaky distributer or faulty breaker (see Test (2) below). Sometimes a fault may be intermittent, in which case its location may not be so simple. This may happen, for example, with a broken wire inside an undamaged covering.

If the engine will not run at all: (1) Test the switch cable for earth by removing the cable and attempting to start engine. (2) If the switch cable proves to be in order, remove the distributer, crank the engine, and test for spark. With magneto ignition, note the safety spark gap or spark from

slip ring; with coil ignition, remove the high-voltage lead, switch on, and test for spark to frame.

(*a*) If good sparking occurs, then magneto or coil, whichever is used, is in order, and distributer must be examined as the probable source of fault.

Distributer.—Examine distributer insulation to detect any evidence of burning, puncturing, cracking or loose-holding nuts. Carbon brush distributer: See that the track is clean; the brass segments are smooth, clean and flush with the insulation; the brush is moving freely in the holder and making good contact. The brush should exhibit a glazed surface and should be examined every 1,000 miles. With spark-gap type distributer, see that all surfaces are clean. With this type ventilation is essential to prevent formation of nitric acid.

(*b*) If sparking is poor or if none occurs with distributer removed in Test (2), there is probably a fault in the magneto or in the coil or battery. The several parts must be examined in detail.

Contact-Breaker.—Examine rocker arm to see if it is sticking owing to swollen fibre bush; examine also spring tension. Examine contacts to see if they are smooth and free from oil. Examine lock-nut and central screw for tightness. Check each contact gap opening. Poor running at low speeds may be caused by dirty or pitted contacts, or by too small contact gap.

Collector Insulator and Slip-Ring (magneto with revolving armature.) Examine insulator to discover any evidence of burning or puncturing. See that

carbon brush makes proper contact. Remove all traces of carbon deposit from insulators. Examine brush connecting conductor in collector insulator with conductor in distributer rotor.

Earthing Brush.—See that this brush makes good contact with the frame.

Faulty Condenser.—An open circuit or break in the condenser causes vicious white sparking at the contact-breaker. A short-circuit in the condenser puts the coil or magneto out of action.

Faults in Windings.—If all the above details are found to be in order, winding faults may be discovered by removing distributer cables and connecting distributer terminals together by a thin wire, the end of which is held about $\frac{1}{32}$ inch from frame. A feeble spark or no spark points to short-circuit or earth in the winding, slip-ring or condenser. The repair may need expert attention.

Dampness, which causes leakage, may be removed by drying out.

Weakening of magnets, which causes weak sparks, may necessitate remagnetisation.

Safety-spark Gap.—See that distance is correct ($\frac{5}{16}$ inch or 8 mm.).

With needle points the spark-over voltage is approximately 1,000 volts per millimetre.

Battery.—With coil ignition, see that the battery is in order.

CHAPTER VI

WIRING SYSTEMS AND LOCATION OF FAULTS

WIRING SYSTEMS

Earth-Return and Insulated-Return Systems.—In order that an electric current can flow in a low-voltage system, there must be a complete metallic circuit. By insulating the parts of the circuit in a suitable manner the current is constrained to flow in its appropriate path. There are two ways in which this can be done. In the one case, insulated cables between the sources of energy and the appliances can be used throughout. This is the insulated-return system. In the other case, an insulated cable is used for one pole only—say, the positive—and the chassis or frame of the vehicle is used for the other pole. This is the earth-return system. Generally speaking, provided the connections to the chassis are sound, the resistance of the earth (or chassis) part of the circuit is negligible, so that if the same cross-section of cable be used with the same voltage in the two cases, the resistance, voltage drop, and cost of cable are twice as great with the insulated as with the earth return. If the same voltage drop in the leads is allowed in the two cases, it follows that the cross-section of the copper in the earth-return system will be half that in the insulated-return system, or the total weight of cable copper will be one-fourth. It is probably this

economy in cable, in addition to its simplicity, that has led to the wide adoption of the earth-return system, while its use for ignition circuits is universal. The advantage claimed for the insulated-return system is reliability, but a precise comparison is hard to establish. It is true that with this system a single failure to earth does not prevent working; whereas if the insulated cable of the earth-return systems breaks down to earth, further working is prevented. On the other hand, it is generally easier to locate wiring faults in the earth-return than in the insulated-return system. Moreover, in the latter system short-circuits between the two cables are always a possible source of trouble.

Importance of Sound Wiring.—Whatever system of wiring is used, good material and good workmanship are essential. Despite the low voltage of the lighting and starting circuits, the working conditions are extremely unfavourable. The chassis of an autocar is not only in a state of continual vibration, but there may be relative movement between the several parts. Care must be taken, therefore, to prevent chafing, rubbing or movement of any kind that will tend to destroy the insulation. Where there is relative movement between parts of the chassis sufficient slack in the cable must be provided. In no case must cable press against a sharp edge or corner, and it is essential to bush with insulating material all holes in metal through which cables pass. Flexible metallic tubing, through which the cables are passed, is a good protection where wear and tear are likely to occur. With high-voltage wires in the ignition system, all these points are particularly

important. Staples and clamps must be carefully insulated and connections properly secured.

To prevent confusion, cables of different colour can be used for the several circuits. Special care must be taken to secure the terminals properly and to ensure that no strain is exerted on the cable. Only stranded cable of high flexibility should be used. Since most wiring faults are due to bad workmanship or bad material, it can be safely asserted that most wiring faults are avoidable. Cable with inferior insulation should not be used.

6-volt and 12-volt Systems. — The standard voltages of automobile lighting and starting systems are 6 and 12 volts. For the same percentage voltage drop, the amount of copper in the 6-volt system is four times that in the 12-volt system. Possibly neither voltage can be conclusively shown to be the better ; the higher voltage has certainly advantages in the design of the machines and switches, owing to the smaller current.

Standard Lighting and Starting Cables.—The British Engineering Standards Association have issued a specification (No. 5002) in this connection, and it is advisable to use cables manufactured in accordance with these standards. It will be noted that there are three types of covering accepted as standard, viz., braided and compounded, armoured, and cab-tyre sheathing (C.T.S.).*

* Since C.T.S. cable is so well suited for car work, and some readers may not be closely acquainted with it, the following notes may be of service :—

Some years ago it was found that the tough rubber compound used for tyres formed an admirable covering and protection for insulated electric cables. Experience has confirmed that such cables, now commonly known as Cab Tyre Sheathed, or

The following particulars are extracted from B.E.S.A. Specification No. 5002 :—

Lighting Cables

Conductors to be of tinned copper wires, 0·012 inch in diameter. Each conductor to be insulated with vulcanised indiarubber not less than 0·25 inch thick. The rubber shall be coloured red on one core, black on the other, in a twin cable ; in a triple cable, white shall be the colour of the smallest.

Types of Covering.—Braided and compounded, armoured ; cab-tyre sheathing. *Braiding and compounding* are to afford protection against water and oil, and to give a smooth, flexible surface. Armouring is to be in form of a close spiral of metal of approximately half-round section not less than 0·015 inch thick. *Cab-tyre sheathing* is to form a circular section.

C.T.S., have many advantages ; for instance, they are water and grease proof, resist the action of oil and petrol, are flexible and easy to install, and are not liable to corrosion. The mechanical properties of these cables are also good.

The usual precaution should, of course, be taken to prevent the cable rubbing against sharp edges, and also to allow sufficient slack where there may be relative movements between parts of the chassis.

For high-voltage leads, C.T.S. cables are superior to cables on which only ordinary rubber insulation is used, experience having shown that the tough rubber covering perishes far less rapidly from the heat of the engine than ordinary rubber. It is essential, of course, with these as with the lighting and starting cables to see that there are no sharp or jagged edges against which the cables can rub. In cases where the cables are taken through metal tubes it is sound practice to bush the holes with insulating material.

To show the value of tough rubber covering as a mechanical protection, it may be mentioned that the same material has also been adopted for strengthening motor inner tubes to reduce the liability to bursting and puncturing.

Lighting Cables with Insulated Return

	Conductor.	Maximum Overall diameter.	
		Braided and compounded, or Armoured.	C.T.S.
Dynamo .	2 × 35/·012 1 × 14/·012	0·38 inch.	0·4 inch.
Battery .	2 × 35/·012	0·37 „	0·39 „
Lamp . .	2 × 14/·012	0·29 „	0·31 „

Lighting Cables with Earth Return

	Conductor.	Maximum Overall Diameter.	
		Braided and compounded, or Armoured.	C.T.S.
Dynamo .	2 × 35/·012	0·37 inch.	0·39 inch.
Battery .	1 × 35/·012	0·225 „	0·25 „
Lamp . .	1 × 14/·012	0·19 „	0·22 „

Starting Cables

Conductor.	Maximum overall diameter.		
	Armoured.	C.T.S.	Braided.
37/·036	0·46 in.	0·495 in.	0·47 in.
61/·036	0·545 „	0·58 „	0·555 „
61/·044	0·63 „	0·69 „	0·64 „

High-Voltage Cables.—It is invariably the custom to provide an earth return for the high-voltage current. For this purpose, the screwed shell of the

sparking plug and one end of the high-voltage winding are connected to the engine or chassis, as the case may be. Consequently the cables that connect the distributer of the magneto or coil to the sparking plugs have to withstand a high voltage to earth, that is, to the metal of the engine, chassis, etc. The maximum value of the voltage between the cables and earth may reach 20,000 volts under certain conditions. The insulation required to prevent a leakage of current to earth, or a short-circuit by puncturing or surface discharge, therefore, must have a much higher insulating property than in low-voltage systems. Pure rubber with a suitable protective covering should be used for this purpose, and great care should be taken to prevent chafing or damage from heat. If the cables are taken through a metal tube, the holes should be carefully bushed and all sharp edges removed. Heat causes rubber to perish rapidly ; it is, therefore, essential not to let the cables be near the exhaust pipe or any other hot part of the engine.

To prevent leakage, the insulation should not be cut back further than is necessary ; the insulation should be carried close up to the terminal or the connecting eye, as the case may be.

Though cheap high-voltage cables are obtainable, the saving in first cost obtained by their use is negligible ; indeed, it is even more inadvisable to attempt economy here than with low-voltage wiring. Experience has proved that only materials of the best quality should be used for the electric circuits of automobiles. Some high-voltage cables have very little protection beyond the ordinary

insulating rubber. This is to be deprecated, for the heat under the bonnet has an injurious effect. It is preferable to employ high-voltage cable with a suitable protective covering, such as tough rubber compound (or cab-tyre sheathing). The thicker the covering the better protected the cable will be, and, therefore, the greater the reliability. For example, high-voltage C.T.S. leads are made in sizes from 4 to 12 mm. in diameter, and it is advisable to use as large a size as possible.

The size of the copper conductor in the high-voltage cable is, electrically, of little importance, for the current is very small. Mechanical strength is the chief factor, and here, as elsewhere on the car, stranded cables should be used.

If the cables are good and are correctly used, the amount of leakage current from them may be negligible. In some cases it is possible to draw sparks from the cables as capacity effect. Also, when the cables are taken through a metal tube, the return current may pass along the tube and spark over a short distance to earth.

To ensure good ignition, leakage should be prevented in any part of the high-voltage system.

It is worth repeating that, with good material and good workmanship, most electrical failures in either the high- or the low-voltage circuits can be eliminated. Whatever the type of automobile, the best electrical equipment and wiring will invariably be found the least costly in the end.

Diagrams of a Typical Wiring System.—For the sake of illustration we shall consider a typical wiring system, with earth return, with starter, dynamo,

battery, lighting, etc., and magneto ignition. Fig. 49 illustrates such a system. It is usual to find such illustrations in instructional handbooks supplied

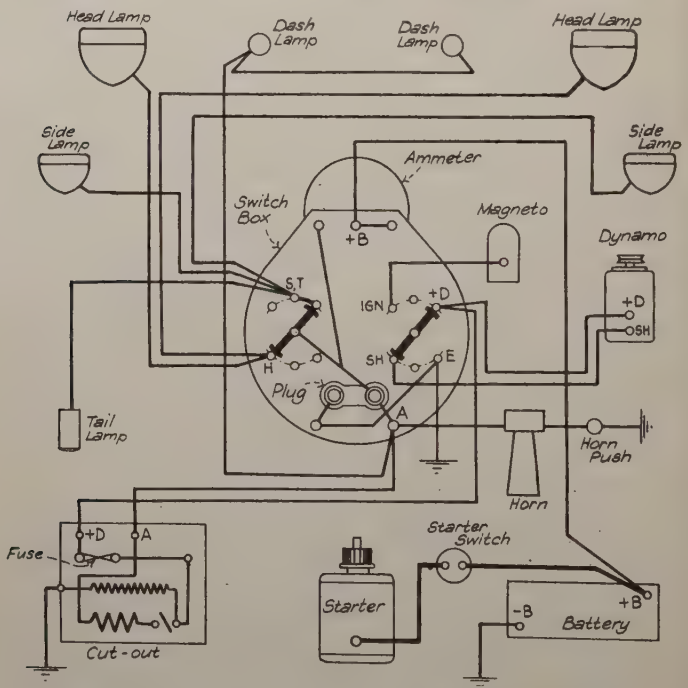

FIG. 49.—Typical earth return wiring system with starter, dynamo, battery, lighting, etc., and magneto ignition.

with automobiles. They may provide useful hints for wiring by showing the terminals to which the several parts have to be connected, but for the car user or repairer their value is less obvious, and in some cases they are unintelligible even to an electri-

cal engineer. Generally speaking, the information contained in a diagrammatic representation of the wiring is insufficient for the driver or repairer of the vehicle ; hence alongside a diagram such as Fig. 49 there should always be a corresponding scheme of connections, as shown in Fig. 50. If such a diagram is not supplied with the car, it should be asked for, or the person interested in the car should make one for himself. To attempt to trace faults, etc., without

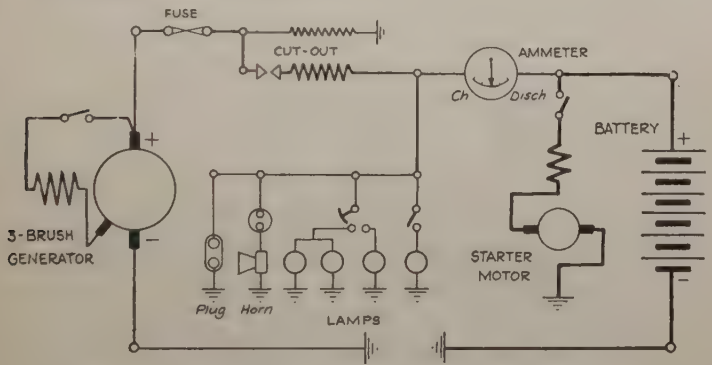

Fig. 50.—Scheme of connections for wiring system in Fig. 49.

a knowledge of the connections may not only be a useless, but even a risky, undertaking for the uninitiated.

The number of wiring arrangements in use is needlessly great, and a genuine effort at standardisation would rapidly reduce the manufacturing costs of electric appliances for automobiles, and thereby cheapen such vehicles, without in any way detracting from their reliability. Standardised wiring, fixings and accessories would even enhance reliability

and simplify repair work. The differences in the numerous diagrams show mainly differences in wiring, switching and other details. If the reader can himself draw out the scheme of connections in Fig. 50 by studying Fig. 49, he can perform a similar exercise for other arrangements. The fundamental principles are the same for all; it is mainly in the arrangement of the parts that differences are introduced.

The appliances can be varied as desired. The ammeter is sometimes omitted. The position of the fuse may differ from that shown. In the position shown in the diagram it is not so useful as a separate fuse in each of the load circuits. Some makers place a fuse in the dynamo field circuit.

Location of Faults in Wiring

Some of the more common wiring faults will now be considered. In this section the battery must be assumed to be in order.

In an *earth*-return (or one-wire) system a wiring fault may be an *earth* (due to an insulation breakdown to earth) or an *open-circuit* (due to a broken wire or cable, loose connection, faulty switch, etc.).

In an *insulated*-return (or two-wire) system, in addition to an earth or an open-circuit, a *short-circuit* may arise from the failure of the insulation between the conductors.

In many instances faults can be detected by careful inspection without the aid of instruments. On the other hand, a fault may be *intermittent* in character; that is to say, it may occur under certain

conditions only. As these conditions in many cases cannot be repeated while a test is being made for the fault, it is often difficult to trace such faults. Thus a broken wire with undamaged insulation may give rise to an intermittent fault which is troublesome to detect.

General Tests for Faults.—Test for an *open-circuit.* Place an ammeter and a cell in the circuit to be tested and close switch (if any). (If a lamp circuit, a lamp which is known to be in order must be placed in the holder.) If the ammeter indicates zero, the fault is probably an open-circuit, traceable to a loose connection, broken or disconnected wire or cable, or faulty switch.

Test for an *earth.* Isolate the circuit by disconnecting the car battery and intentional earth connections (by removing lamps, etc., in an earth-return system) and connect the negative of a cell to the wiring, and the positive of the cell to the positive of a 3-volt voltmeter, the other pole of which is earthed. A reading on the voltmeter indicates an earth. If a switch is part of the wiring, the test should first be made with the switch open, and then with the switch closed, with a view to locating the earth fault.

Test for a *short-circuit.* This fault is possible in the wiring of an insulated-return system. Carry out test as for open-circuit, but with the lamp removed, or any other piece of apparatus disconnected. A reading on the ammeter indicates either a fault to earth on both positive and negative leads, or a short-circuit between these conductors. To determine whether the fault is an earth or a short-circuit, carry

out the test for an earth. No reading on the voltmeter indicates that the fault is a short-circuit.

If no suitable voltmeter is available, a test lamp, rated for the voltage of the test cell (or battery) employed, may be used for making the tests for an earth or short-circuit.

Faults in Starting-Motor Circuit.—If the motor will not run, or only crawl, connect a suitable voltmeter to the motor terminals and press the starting switch just long enough to observe the instrument. *No* reading indicates an *open*-circuit in the starting switch or in the wiring to the battery. If a *very low* reading is obtained, look for loose connections at the battery, switch or motor, for an earth or a short-circuit in the wiring, or for a short-circuit in the motor (see under " Location of Faults in Machine Windings "). If a reading *equal* to the battery voltage is obtained, the motor is open-circuited (see under " Location of Faults in Machine Windings "). In this case the motor will not run.

When the motor will not move on switching on, an indication of the nature of the fault may be obtained from the headlights as follows: If on closing the starting switch the lights do not become dim, an open-circuit is indicated. If the lights do become dim, a short-circuit or an earth is indicated.

Faults in Generator Circuit.—These are generally made evident by the absence of the proper indication of the charging current. Connect a suitable voltmeter (range, 0 to 30 volts) across the generator terminals, remove the leads from the battery, open all switches except the dynamo field switch (if one be provided), and run the engine and dynamo at

normal speed. If the voltmeter now shows a reading in excess of 6 or 12 volts, as the case may be, with the battery thus isolated, the generator is in order and the trouble must be sought in the external wiring or accessories beyond the switches, or it may be that the cut-out refuses to act. If only a low voltage or no voltage at all is obtained, disconnect the external leads from the generator, keeping the field circuit closed. If a high reading is now obtained, the fault is to be looked for in the disconnected leads or cut-out (earth or short-circuit); if disconnecting the leads makes no difference, the fault is most likely in the generator (see under "Location of Faults in Machine Windings").

A fault beyond the cut-out may cause violent current oscillations through the circuit being closed by the cut-out as the generator voltage rises, and then being opened as the voltage drops to zero, owing to the rush of current into the fault. Since in the nature of things this excessive current, once the fault exists, goes on repeating itself, bad pitting at the cut-out contacts inevitably ensues.

Loose connections, a dirty commutator, or brush faults may also cause the ammeter needle to oscillate.

Faults in Lighting Circuits.—If all the lights fail when all switches are closed, see if opening or closing any of the lamp switches makes a difference. If it does, a faulty branch circuit is indicated. If not, a fault in the circuit between battery and distribution board is indicated. Having located the faulty circuit, carry out the tests described on p. 115 for open-

circuit, earth, or short-circuit. If only one lamp fails, examine for a burnt-out lamp by trying a lamp known to be in order. Should this lamp not light, examine the faulty circuit for open-circuit, earth, or short-circuit as explained on p. 115.

Faults in Horn and Other Branch Circuits.—Proceed as for faults in lighting circuits.

Faults in Cut-Out.—In addition to the electrical faults already referred to, there is always a possibility of the contacts refusing to open or to close. A smart tap may often suffice to make the cut-out operate, but the contacts may need attention from time to time. It is well to cultivate the habit of observing the ammeter needle in the same way as the oil gauge, particularly when the engine is stopped, to ensure that the battery is not left to discharge through the generator armature because the cut-out has failed to open the circuit, nor through the coil because the ignition switch has not been opened.

Location of Faults in Machine Windings

Field Winding Faults.—Discontinuity and earth faults in the field circuit of a machine can both be traced by isolating the coils and applying tests similar to those described for the wiring system. A short-circuit between adjacent turns in a coil causes the resistance between its terminals to be lower than that of a healthy coil. If two or more such coils are, therefore, connected in series with a testing battery, and the voltage across each coil be compared, the voltage measured across the coil with some of its turns short-circuited will be lower than that across

a healthy but otherwise similar coil; while no reading on the voltmeter is indicative of a complete short-circuit. A reading equal to the voltage of the testing circuit would show that there is an open-circuit in this coil. To locate a coil which is earthed, proceed exactly as directed for an earth fault in the wiring.

Brush and Commutator Faults.—After removing the cover (if any), make a careful examination to ensure that all brushes are bedding properly. Trouble may arise from worn brush, brush sticking in holder, defective spring, insufficient spring tension, or earthed brush-holder or brush flexible.

Examine the commutator for carbon deposit or oil, and see that the micas between segments are not short-circuited by carbon or dirt.

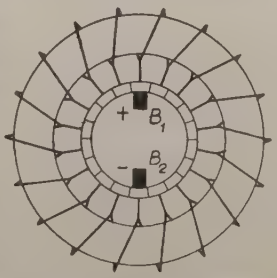

FIG. 51.—Closed-circuit two-pole ring winding for direct-current armature.

Armature Faults.—When an armature develops a fault, we may wish to diagnose the fault and locate its exact position, although the repair of most armature faults is generally a job for the makers or for some one with skill and experience of such work. Direct-current armatures have closed-circuit windings, *i.e.*, the end of the one coil is joined to the beginning of the next, and so on throughout, to form a closed circuit. This can be represented diagrammatically by the two-pole ring armature shown in Fig. 51. Connections to the commutator are tapped

on to the coils; it will be seen that there are two paths in parallel between the positive and negative brushes B_1 and B_2. In an actual machine the wire is wound into coils, which are carefully insulated and placed in slots round the circumference of the cylindrical or drum-shaped armature core. Fig. 52 shows two coils of such a drum armature with the connections to the commutator. Only one turn per coil is shown, but on a small armature there are many turns in a coil between adjacent commutator segments. The connections shown in Figs. 53 and 58 and the following notes refer to a two-pole armature in which there are two paths in parallel between brushes placed 180 degrees apart, but the principles may be applied to machines with any number of pairs of poles and armature paths.

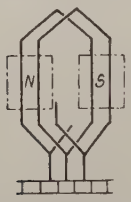

FIG. 52.—Typical coils of a drum-wound armature with connections to commutator.

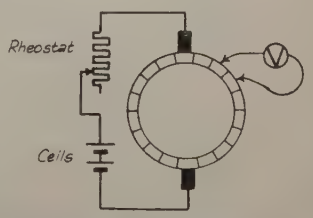

FIG. 53. — Connections for locating open-circuit in an armature coil.

(1) *Open-Circuit (or Break) in an Armature Coil.*—Make the connections as in Fig. 53, in which a 6- or 12-volt battery with regulating resistance is shown connected in circuit with the faulty armature. A low-reading voltmeter is attached to a pair of leads so that the voltage between adjacent segments all round the commutator can be read. It will be found

that if the armature is kept stationary relative to the brushes, no reading of the voltmeter will be obtained between any pair of adjacent segments in that section of the armature included between the

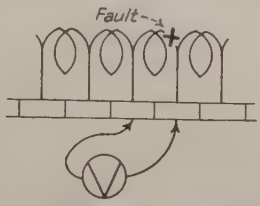

FIG. 54.—Location of open-circuited coil in Fig. 53 by indication on voltmeter when placed across fault.

two brushes in which the fault lies, EXCEPT between the segments connected to the faulty coil. This is explained by the diagram in Fig. 54. If there should be more than one break, then this test will give a negative result and the connections shown in Fig. 55

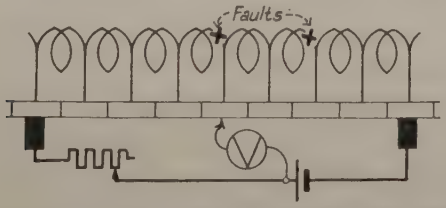

FIG. 55.—Connections when more than one armature coil is open-circuited.

must be made. The voltmeter should be kept fixed while the armature is moved slowly. As soon as a faulty coil enters the section between the voltmeter connection and the right-hand brush, the reading will fall to zero. The coil should be repaired, or the segments to which it is connected should be tem-

porarily bridged across and the test continued in the same way to locate other open-circuited coils.

(2) *Open-Circuit (or Break) between a Coil and Commutator Segment.*—This is a very common fault in small armatures. Connect as in diagram in Fig. 53 and proceed as before to measure the voltage between commutator segments. In Fig. 56 the disconnection is shown in the lead connecting a pair of coils to segment *b*. It will be found that the testing voltmeter gives the same reading when connected between any pair of adjacent segments,

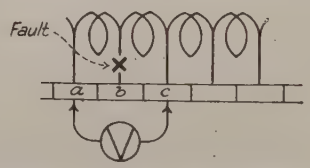

Fig. 56.—Location of open-circuit between a coil and a commutator segment. Between *a* and *b* or *b* and *c*, voltmeter reading is zero. Between *a* and *c* voltmeter reading equals twice voltage between segments.

except between bars *a* and *b*, and again between *b* and *c*, where no reading is obtained. Between bars *a* and *c* about twice the normal voltage between segments will be observed.

In an armature that has failed faults (1) and (2) may both be present, in which case fault (1) will manifest itself in the first instance.

(3) *Short-Circuited Coil.*—This condition is shown in Fig. 57. Connect as in Fig. 53 and measure voltage between segments. A reduced voltage between a pair of segments indicates a short-circuit or a partial short-circuit. A voltmeter range 0 to

0·1 volt may be required for this test, and care must be taken to obtain good contact between the voltmeter leads and the commutator bars.

(4) *Earth Fault.*—Before testing the armature winding the brush-holders should be carefully examined and tested for a possible earth fault. The test for an earth may be conveniently carried out as directed for the wiring system (p. 115), a piece of paper being inserted between each brush and the commutator to insulate the armature from the brushes and brush-holders.

To locate the faulty coil when an earth has been

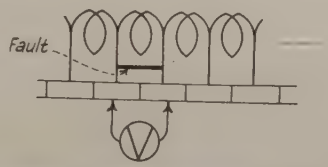

FIG. 57.—Location of short-circuited coil, indicated by reduced voltage between segments.

traced to the armature winding, connect the testing battery and regulating resistance to the armature terminals, one terminal of the testing voltmeter to earth and the other voltmeter terminal to a lead which can be connected to every commutator bar in turn, as in Fig. 58. Take readings of the voltage between each segment and earth. On passing from bar to bar, if there is an earthed coil, the voltmeter reading will decrease as a certain segment (or pair of segments) is approached, and will be zero or reach a minimum value at this place. The voltage will rise again when this segment is passed, but now it will be in the opposite direction. Since an armature

has more than one circuit, the earthed coil may or may not be connected to the segment thus located. When such a segment is found, therefore, the voltmeter connection should be kept in contact and the armature rotated relatively to the brushes. If this movement of the armature does not alter the voltmeter reading, then this segment is earthed or is the one nearest in contact to the earthed coil. If movement of the armature changes the voltmeter reading,

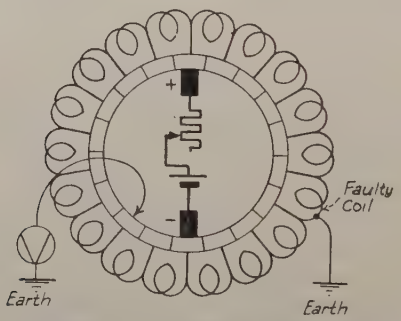

FIG. 58.—Location of earth fault, showing supply connections and testing voltmeter.

this segment is not earthed, and the test must be continued until a segment is found on which the minimum voltage to earth is independent of its position relative to a brush.

A clue to the position of a fault is often obtained by inspection of a commutator. Flashing takes place between a brush and a segment associated with a disconnection fault (open-circuit). With an earth-return system, an earthed coil causes a short-circuit when the segment to which it is connected passes under a brush joined to the insulated side of the

system. Consequent sparking causes burning of the brush and the segment, the latter often becoming covered with a deposit of carbon.

In a dynamo and in a motor a short-circuited coil usually burns out because of the heavy induced current in the short-circuited turns. The appearance of the burnt and damaged insulation is often a guide to the faulty section.

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LONDON AND TONBRIDGE

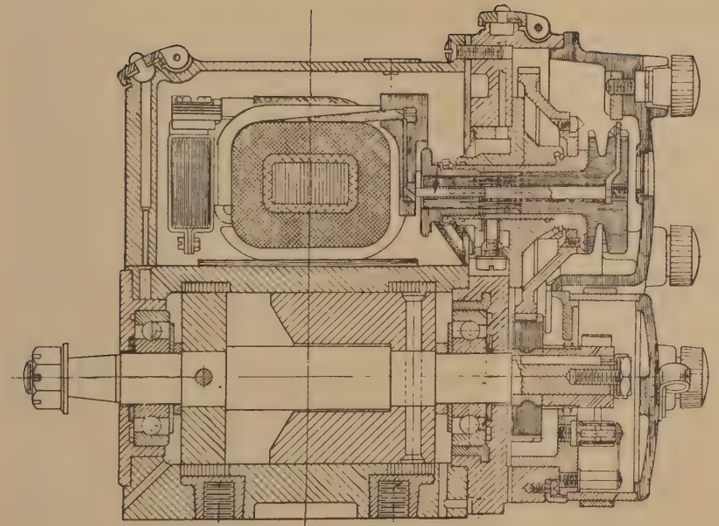

FIG. 44.—Polar inductor magneto.

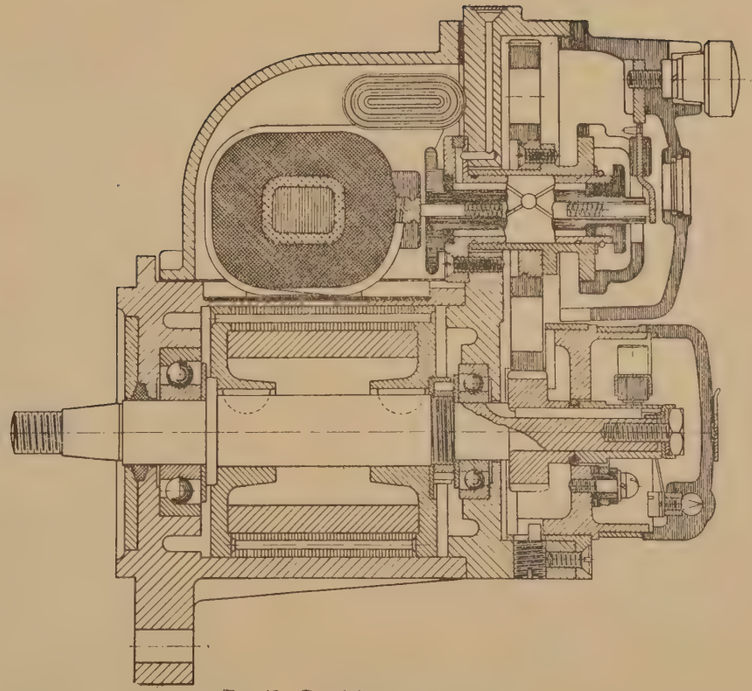

FIG. 42.—Revolving-magnet magneto.

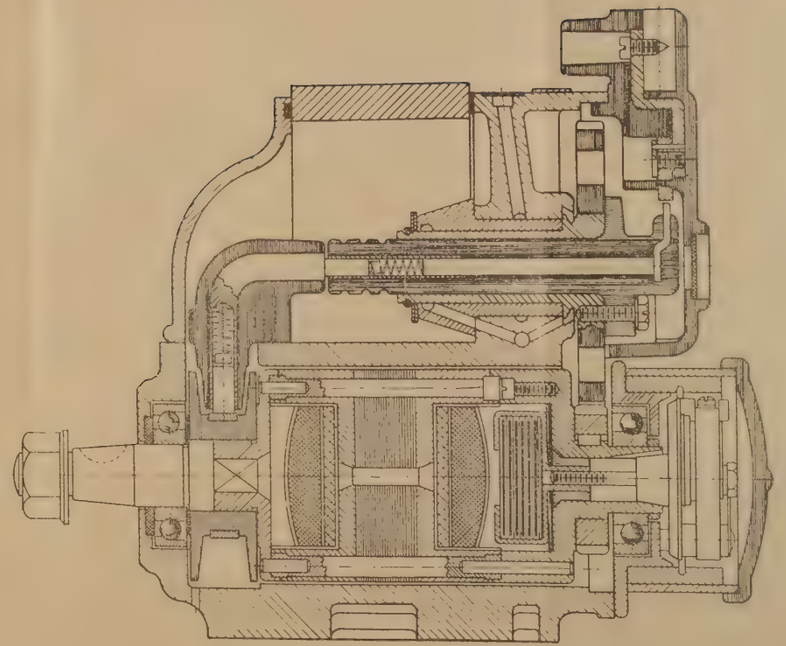

FIG. 39.—Revolving-armature magnets.

ignition system

commutator

importance of clean plugs.

sulphation

charging circuit

magnet steel

cab-tyre sheathing

armature reaction

location of ignition faults

faults in generator circuit

polar-inductor magneto

safety spark gap

desulphation

battery-coil ignition

capacity of a cell